

An Overview Of NASA Automotive Component Reliability Studies

Microelectronics Reliability & Qualification Working Meeting

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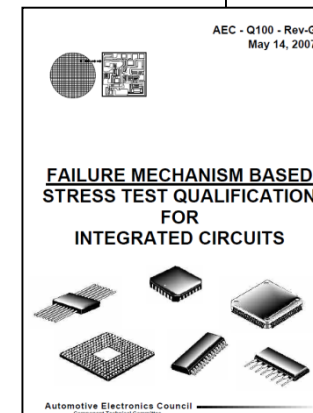
Acronyms

| Acronym | Definition |
|----------|--|
| Aero | Aerospace |
| AFRL | Air Force Research Laboratory |
| BME | Base Metal Electrode |
| BOK | Body of Knowledge |
| CBRAM | Conductive Bridging Random Access Memory |
| CCMC | Community Coordinated Modeling Center |
| CDH | Central DuPage Hospital Proton Facility, Chicago Illinois |
| CMOS | Complementary Metal Oxide Semiconductor |
| CNT | Carbon Nanotube |
| COP | Community of Practice |
| COTS | Commercial Off The Shelf |
| CRÈME | Cosmic Ray Effects on Micro Electronics |
| DC | Direct Current |
| DLA/DSCC | Defense Logistics Agency Land and Maritime |
| EEE | Electrical, Electronic, and Electromechanical |
| ELDRS | Enhanced Low Dose Rate Sensitivity |
| EP | Enhanced Plastic |
| EPARTS | NASA Electronic Parts Database |
| ESA | European Space Agency |
| FPGA | Field Programmable Gate Array |
| FY | Fiscal Year |
| GaN | Gallium Nitride |
| GSFC | Goddard Space Flight Center |
| HUPTI | Hampton University Proton Therapy Institute |
| IBM | International Business Machines |
| IPC | International Post Corporation |
| IUCF | Indiana University Cyclotron Facility |
| JEDEC | Joint Electron Device Engineering Council |
| JPL | Jet Propulsion Laboratories |
| LaRC | Langley Research Center |
| LEO | Low Earth Orbit |
| LLUMC | James M. Slater Proton Treatment and Research Center at Loma Linda University Medical Center |
| MGH | Massachusetts General Hospital |

| Acronym | Definition |
|------------|--|
| MIL | Military |
| MLCC | Multi-Layer Ceramic Capacitor |
| MOSFETS | Metal Oxide Semiconductor Field Effect Transistors |
| MRAM | Magnetoresistive Random Access Memory |
| MRB | Material Review Board |
| MRQW | Microelectronics Reliability and Qualification Working Meeting |
| MSFC | Marshall Space Flight Center |
| NASA | National Aeronautics and Space Administration |
| NAVY Crane | Naval Surface Warfare Center, Crane, Indiana |
| NEPAG | NASA Electronic Parts Assurance Group |
| NEPP | NASA Electronic Parts and Packaging |
| NPSL | NASA Parts Selection List |
| PBGA | Plastic Ball Grid Array |
| POC | Point of Contact |
| POL | Point of Load |
| ProCure | ProCure Center, Warrenville, Illinois |
| QPL | Qualified Product List |
| QML | Qualified Manufacturers List |
| RERAM | Resistive Random Access Memory |
| RF | Radio Frequency |
| RHA | Radiation Hardness Assurance |
| SAS | Supplier Assessment System |
| SEE | Single Event Effect |
| SEU | Single Event Upset |
| SiC | Silicon Carbide |
| SME | Subject Matter Expert |
| SOC | Systems on a Chip |
| SOTA | State of the Art |
| SPOON | Space Parts on Orbit Now |
| SSDs | Solid State Disks |
| TI | Texas Instruments |
| TMR | Triple Modular Redundancy |
| TRIUMF | Tri-University Meson Facility |
| VCS | Voluntary Consensus Standard |
| VNAND | Vertical NAND |

Overview - Automotive Electronic Parts

- In US, supplied in accordance with Automotive Electronics Council (AEC) specifications
- AEC URL: <http://www.aecouncil.com/> Documents are FREE
- NEPP evaluation objectives:
 - Procure sample parts and evaluate **as received performance and parametric compliance**
 - Perform burn-in and life test to evaluate reliability
- Naval Surface Warfare Center (NSWC) Crane Indiana, providing test capabilities
- Parts selected:
 - chip capacitors, ceramic and dry slug tantalum
 - discrete semiconductors
 - microcircuits
- Initial results on capacitors showed unexpected behavior
- Finding subtle, non obvious differences, COTS to Aerospace Hi Rel and COTS to COTS
- Typically auto is just one grade of COTS offered



You May Think the “Big Three” Would Directly Oversee US Standards for Automotive Grade EEE Parts, But...

Chrysler

Ford

GM

Automotive Electronics Council (AEC) Controls the AEC “Q” Specifications for Automotive EEE Parts

Sustaining Members

MAGNA ELECTRONICS
BOSE
Visteon
HELLA
LEAR Corporation
DENSO
Autoliv
John Deere
Cummins
TRW
Continental
DELPHI
Valeo
GENTEX Corporation
HARMAN

Technical, Associate and Guest Members

KERMET
LATTICE
Littelfuse
MXIC
Maxim Integrated
Microchip
Micron
muRata
NXP
Freescale
Fujitsu
INDIUM Corporation
Infineon
International Rectifier
ISSI
ON Semiconductor
Peregrine Semiconductor
PERICOM
RENESAS
SMIC

SPANSION
STMicroelectronics
TDK
AEROSPACE
ALTERA
AMRDEC
Analog Devices
AM
CIRRUS Logic
CYPRESS
DfR Solutions
Fairchild Semiconductor
Texas Instruments
TSMC
Tyco Electronics
VISHAY
Winbond
Xilinx

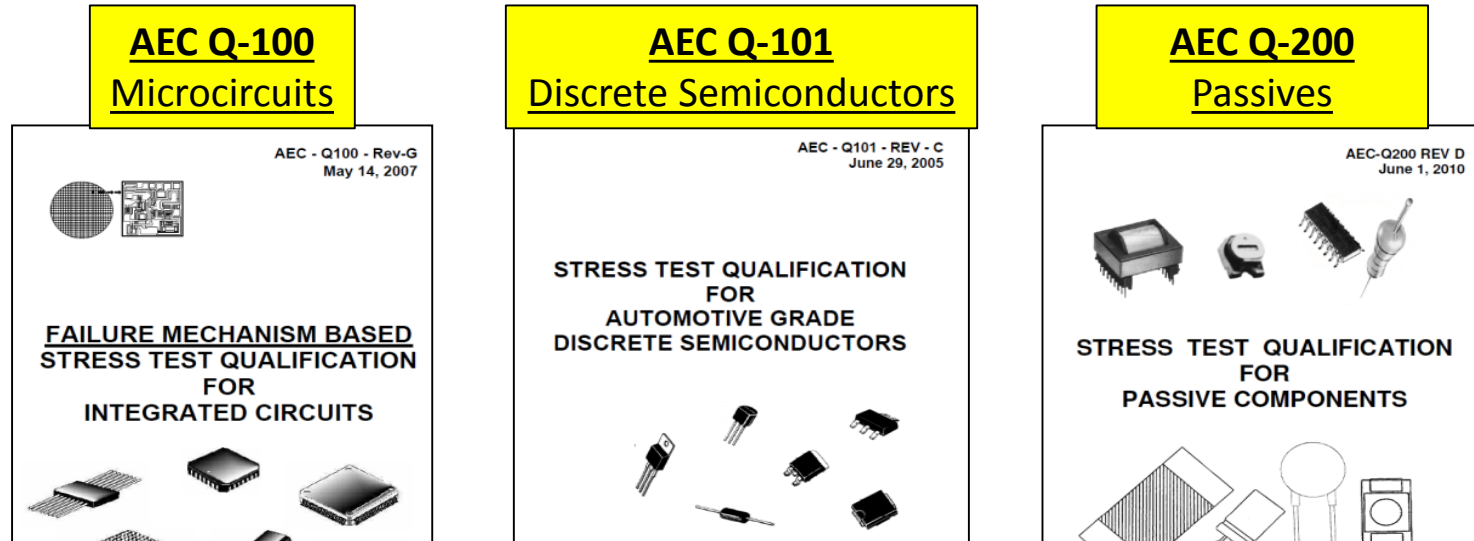
So Why Automotive Parts for Space?



- Parts from manufacturers that are qualified to the AEC Q specifications have advantages
 - Similar parts from different manufacturers have to be capable of meeting the same qualification, so they can be expected to have similar performance and reliability
 - Same form, fit, function – maybe!
- Reliability problems more likely to become public knowledge than similar problems for general purpose commercial (large, homogenous market)
- They are cost competitive to catalog COTS

Automotive Electronic Parts

In US, Automotive Grade EEE Parts are **qualified** in accordance with Automotive Electronics Council (AEC) specifications “AEC Q”



| Grade | Temperature Range | AEC 100 Microcircuits | AEC 101 Discrete Semiconductors | | AEC 200 Passives |
|-------|-------------------|-----------------------|---------------------------------|------|------------------|
| | | | Except LEDs | LEDS | |
| 0 | -40°C to +150°C | X | — | — | X |
| 1 | -40°C to +125°C | X | X | — | X |
| 2 | -40°C to +105°C | X | — | — | X |
| 3 | -40°C to +85°C | X | — | X | X |
| 4 | 0°C to +70°C | X | — | — | X |

AEC Specification System

A Brief Overview

- Key Features of the AEC System include:
 - A uniform and structured approach for Qualification of a Device Family
 - **No requirements for screening**
 - Requirements for Requalification in the event of major changes to materials, processes etc.
 - An Expectation (not requirement) for:
 - Certification to ISO 16949
 - A Production Part Approval (PPAP) document published by the Automotive Industry Action Group (AIAG) as required by ISO 16949

No Pure Tin Prohibition

ISO TS 16949

TECHNICAL
SPECIFICATION

ISO/TS
16949

Third edition
2009-06-15

- A Quality Management System specifically for automotive production
- Certification by a third party
- Augmented by periodic audits by the automobile manufacturers and their sub-system suppliers

Quality management systems —

**Particular requirements for the application
of ISO 9001:2008 for automotive production
and relevant service part organizations**

Systèmes de management de la qualité —

*Exigences particulières pour l'application de l'ISO 9001:2008 pour la
production de série et de pièces de rechange dans l'industrie automobile*

What is a Production Part Approval Process (PPAP)?

- A PPAP is a data package required for compliance with ISO 16949
- The current revision is the 4th edition, dated June 2006
- The PPAP consists of 18 elements
 - No standard format; depth of content varies widely between manufacturers
 - Manufacturer decides elements to make readily available versus “on-site” only
- Examples of the elements:
 1. Design records
 2. Engineering Change Documents
 3. Design Failure Modes and Effect Analysis (DFMEA)
 4. Process Flow Diagram
 5. Process Failure Modes Effect Analysis (PFMEA)
 6. Control Plan
 7. Records of Material/Performance Tests
 8. Initial Process Studies
 9. Qualified Laboratory Documentation
 10. Sample Production Parts
 11. Customer-specific requirements
 12. Parts Submission Warrant (PSW)

| PPAP Levels | PPAP Submission Requirements |
|-------------|---|
| 1 | Product Submission Warrant only (and for designated appearance items, an Appearance Approval Report) submitted to customer |
| 2 | Product Submission Warrant with product samples and limited supporting data submitted to customer |
| 3 | Product Submission Warrant with product samples and complete supporting data submitted to customer. |
| 4 | Product Submission Warrant and other requirements as defined by customer. |
| 5 | Product Submission Warrant with product samples and complete supporting data reviewed at organization's manufacturing location. |

NEPP Evaluation of Automotive EEE Parts

The Plan

- Procure sample Automotive Grade EEE parts
 - Procure via authorized distribution or direct from manufacturer
 - Parts advertised by supplier to meet “AEC Q” requirements
 - Ceramic chip capacitors (base metal electrode from 3 different suppliers)
 - Discrete semiconductors (2 diodes, 1 transistor, 1 transient voltage suppressor)
 - Microcircuits (1 digital, 1 linear)
- Evaluate **as received performance and parametric compliance**
 - Perform burn-in and life test to evaluate reliability
 - Naval Surface Warfare Center (NSWC) Crane Indiana provides testing

Cost Comparison Data and Discussion

- Automotive parts are inexpensive but large minimum order quantity purchases can be required - into the thousands.
- No radiation data available for automotive EEE Parts
- Additional screening costs (including radiation assurance) may be required to meet mission requirements before automotive parts can be used in low risk space applications
- Need to consider the full cost of ownership if cost is the driver

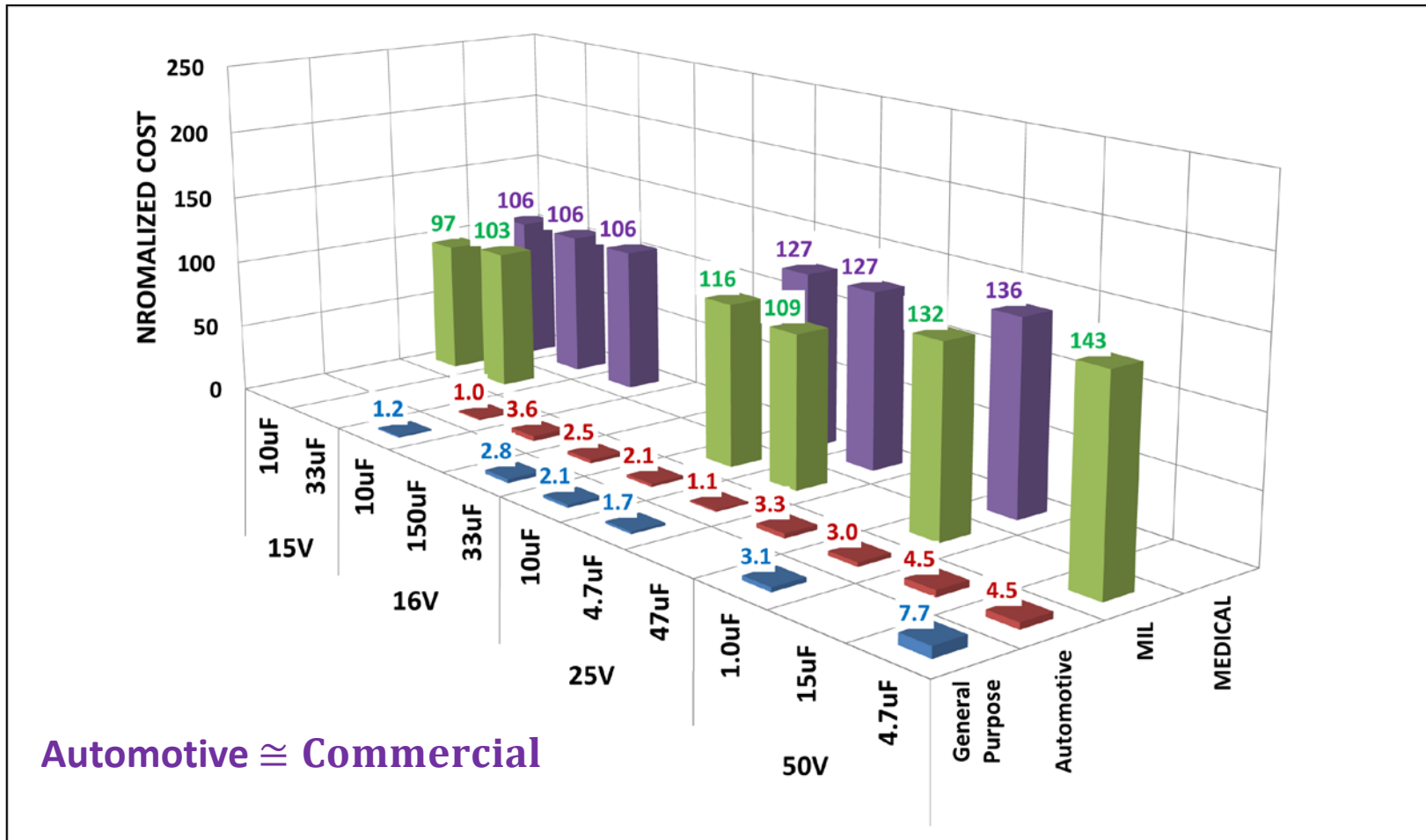
Tantalum Chip Capacitors

AVX Catalog S-TL0M714-C

Tantalum Chip Capacitor-AVX

Tantalum Chip Capacitors

Normalized Cost Comparison for Selected Ratings



Ceramic Chip Caps

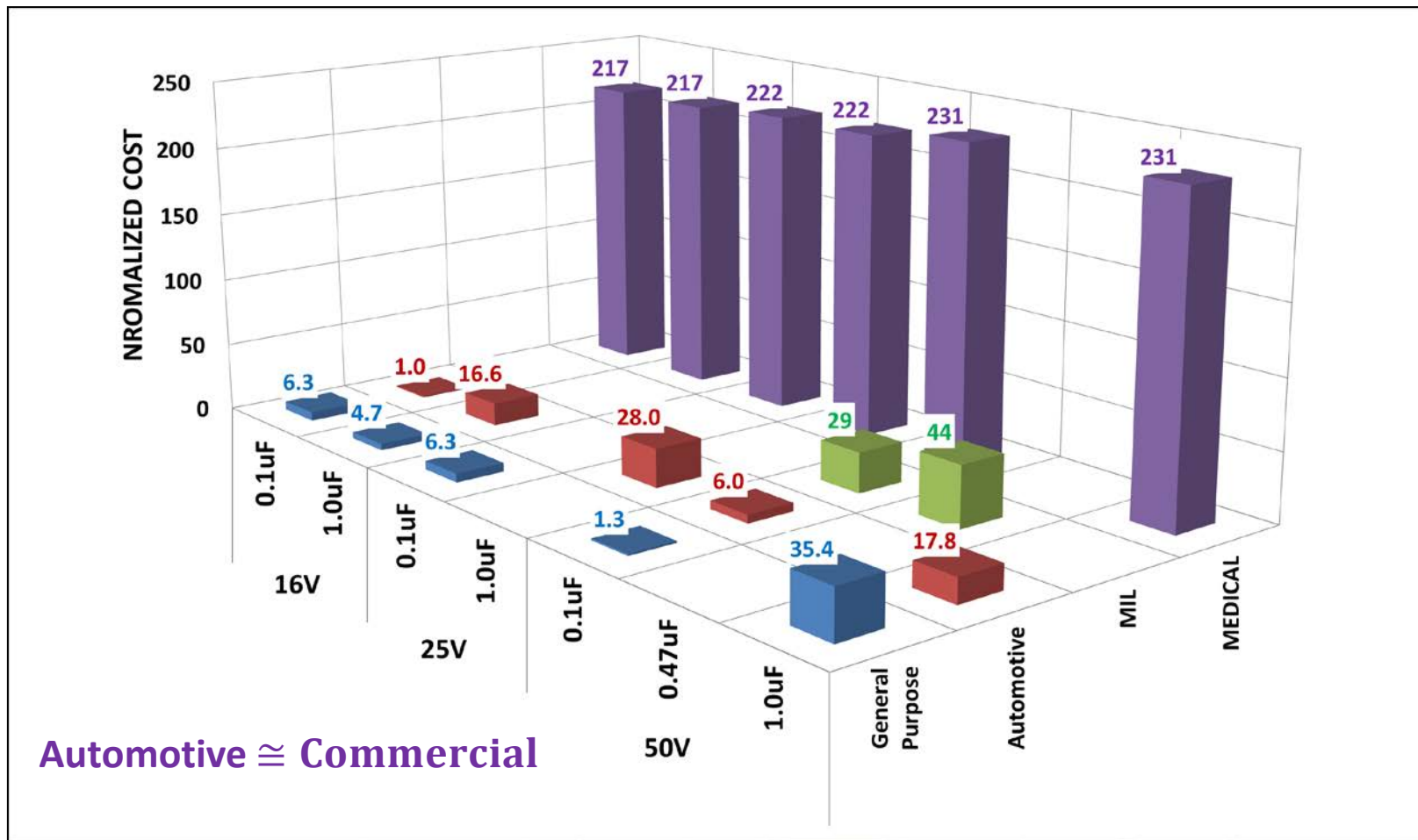
MULTICOMP Ceramic Capacitors

U2J Class 1 Multilayer Ceramic Capacitors

AVX Catalog S-MLCC0414-C

Ceramic Chip Capacitors

Normalized Cost Comparison for Selected Ratings



Testing Summary: NEPP Evaluation Automotive Parts Ceramic Capacitors

Parts were purchased through distributors as Automotive Electronics Council (AEC) Q-200 Automotive Grade

| Commodity | Test | Status | Comments |
|---|---------------------------------|--|---|
| 0805 Size 0.47uF, 50V 3 Different Mfrs All Use BME Technology | Construction Analysis | Complete | <ul style="list-style-type: none"> All 3 Lots use BME Technology At their own discretion a manufacturer supplied devices made with "flexible termination" |
| | Initial Parametric Measurements | Complete | <ul style="list-style-type: none"> No Failures DWV known to produce negative cap shift <ul style="list-style-type: none"> Mfrs recommend bake-out to restore cap |
| | Life Test* (2x Vrated, 125°C) | > 8000 Hrs Complete (Progressing to 10k hours) | <ul style="list-style-type: none"> 1 lot exhibits 8 catastrophic short life test failures (120pc) 2 fail @ 3.1k hrs; 3 fail @ 4.7khrs; 1 fail @ 6.2khrs ; 2 fail @7khrs 2 other lots starting to exhibit IR degradation after 7.5khrs |
| 0402 Size 0.01uF, 16V 3 Different Mfrs 2 BME & 1 PME | Construction Analysis | In Process | <ul style="list-style-type: none"> 2 Suppliers advertise BME and 1 advertises PME |
| | Initial Parametric Measurements | Complete | <ul style="list-style-type: none"> No Failures |
| | Life Test* (2x Vrated, 125°C) | > 2000 Hrs Complete (Progressing to 10k hours) | <ul style="list-style-type: none"> No Catastrophic Failures PME lot has most stable IR through 2k hrs Both BME lots showing initial signs of Hot IR degradation at ~500 Hrs |

BME = Base Metal Electrode
 DWV=Dielectric Withstanding Voltage
 IR = Insulation Resistance
 PME = Precious Metal Electrode

* MIL requires 2000hrs, 0 failures for qualification

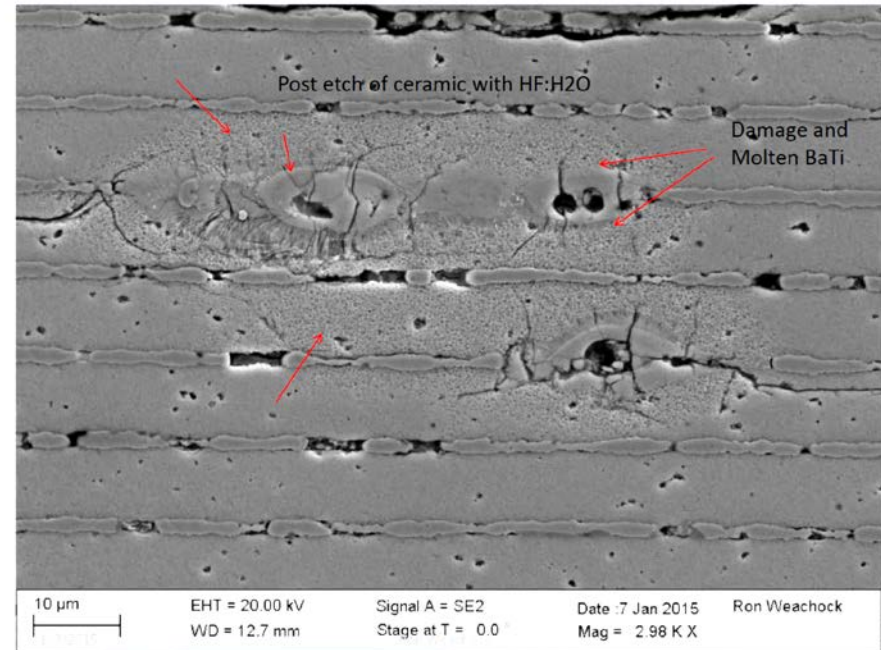
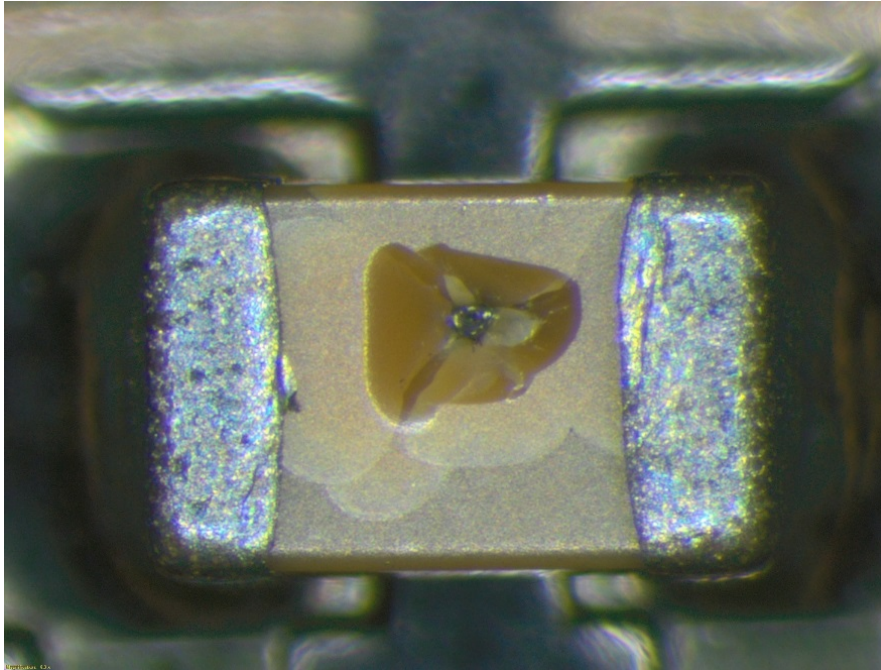
Testing Summary: NEPP Evaluation Automotive Parts ICs and Discrete Semiconductors

Parts were purchased through distributors as Automotive Electronics Council (AEC) Q-100 and Q101

| Commodity | Test | Status | Comments |
|---|---------------------------------|------------|---|
| Integrated Circuits 2 Different Mfrs 1 Diff Bus Transceiver 1 Comparator | Construction Analysis | In Process | <ul style="list-style-type: none"> • Mold Flash and/or FOD on Terminals "As-Received" (Linear IC) • Tg measurements complete • CSAM complete for digital IC • CA to be performed at end of life test |
| | Initial Parametric Measurements | Complete | <ul style="list-style-type: none"> • No Failures |
| | Burn-In & Life Test* | In Process | <ul style="list-style-type: none"> • Differential Bus Transceiver Life Test RESTART Pending. Initial Life Test Aborted due to Insufficient Decoupling Capacitance. • Comparator Burn-In Complete. Life Test Pending |
| Discrete Semiconductors 1 Bipolar transistor (dual) 1 Switching diode 1 Transient Voltage Suppressor 2 Schottky Diodes | Construction Analysis | In Process | <ul style="list-style-type: none"> • Tg measurements complete • CA to be performed at end of life test |
| | Initial Parametric Measurements | In Process | <ul style="list-style-type: none"> • No Failures for bipolar transistor • Switching diode to be tested 07/15 |
| | Burn-In & Life Test* | In Process | <ul style="list-style-type: none"> • Bipolar transistor – 3500 hours of life test completed (20 pcs) – No Failures To Date, 5500 hours read point pending • Switching diode test start delayed due to parts ordering issue |

Example of Catastrophic Life Test Failure

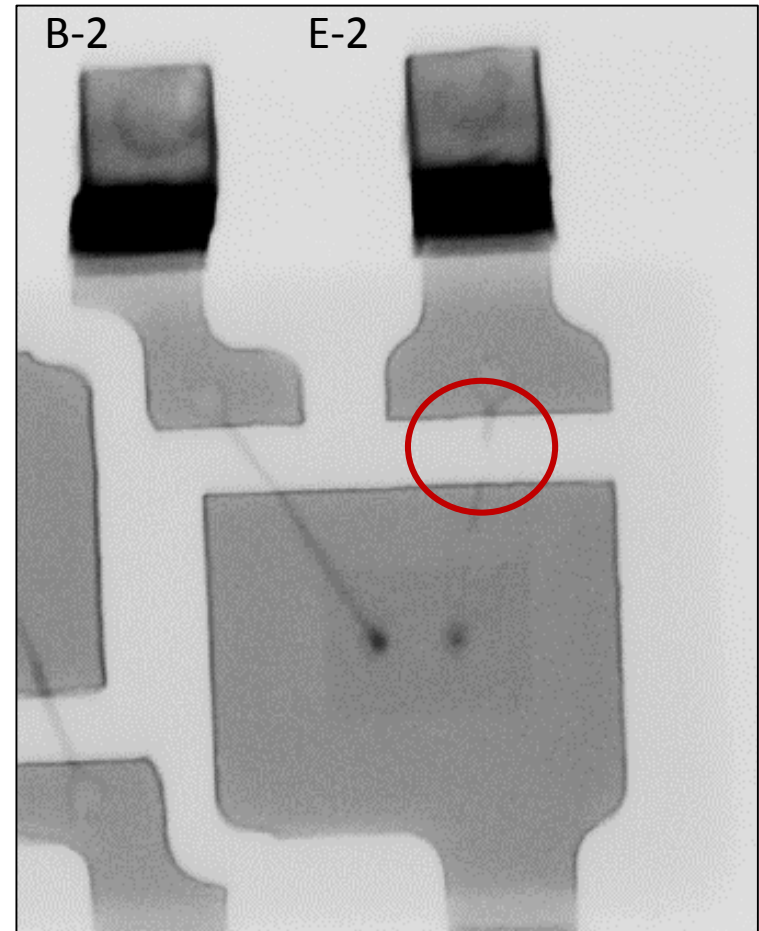
Mfr "A" Ceramic Chip Capacitor - Short Circuit



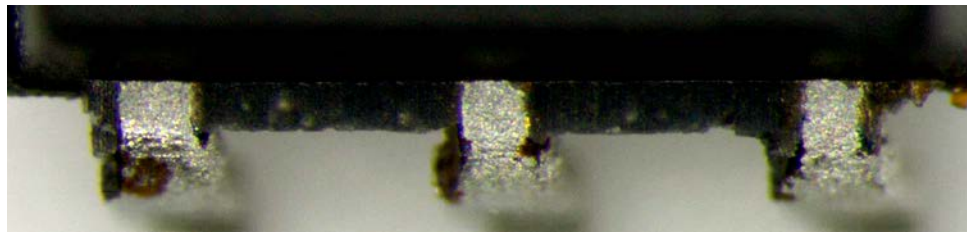
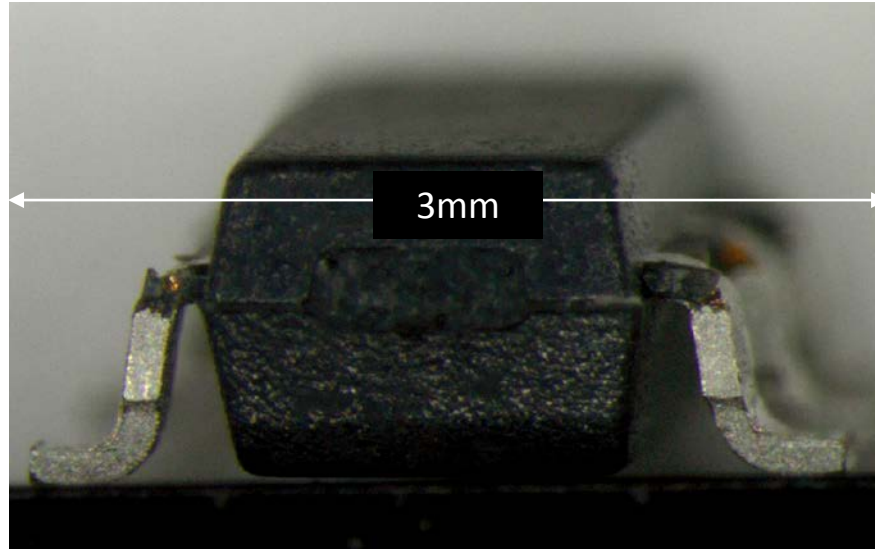
A total of 8 similar appearing catastrophic failures observed through 7500 hours of testing

Bipolar Transistor Failure Initial Analysis Results

- X-ray Top View Showing Fused Open Bond Wire
- Testing hook-up error suspected
- Electrical over-stress likely
- Learning lessons about how to test as well as how well parts perform!!!



Observations from Receiving Inspection FOD* on IC Terminations “As-Received”



* Excess molding compound escaping between mold halves and mold to leadframe interfaces. Small size makes it difficult to remove this flash automatically. **Considered acceptable for automotive users, NASA would normally reject to a Materials Review Board (MRB) for disposition, so NASA accept/reject criteria probably need review.**

Digital Microcircuit Initial Failure Analysis

- Hi Speed Comparator
- All parts failed dynamic burn-in soon after turn-on
- Investigation complete
- **Parts Overstressed**
- Combination of test frequency and temperature used, exceeded part rating and led to thermal runaway
- Revised test conditions in development
- Human Error/Learning Curve

Lessons Learned

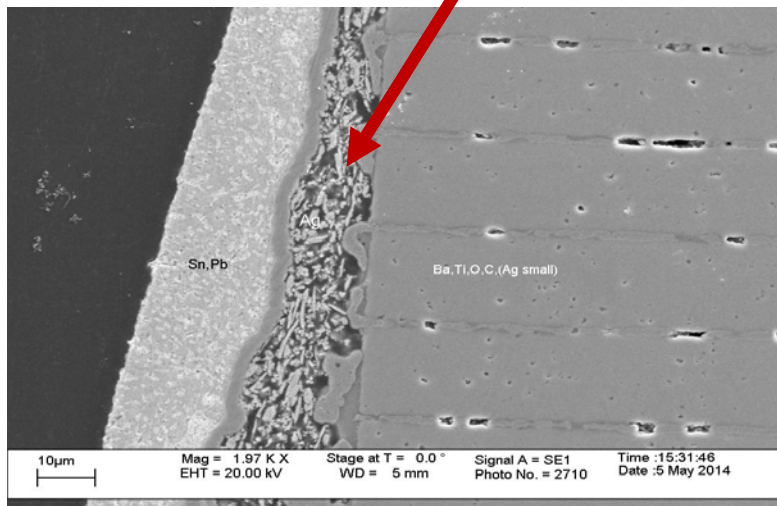
Procurement of Automotive EEE Parts Lessons Learned (1)

- Anybody can buy catalog “AEC Q” parts via authorized distributors
- However, many large volume automotive electronic system manufacturers DO NOT buy “catalog” automotive grade EEE parts
 - Instead, they procure via internal SCDs based on “AEC Q” catalog items
 - SCDs used to tailor and control specific needs (e.g., unique test requirements, internal part numbers)
- Some distributors demonstrated no knowledge of AEC components and suggested other parts they had in stock as replacements
- Traceability needs careful control – distributor documentation may not have same details as manufacturer’s

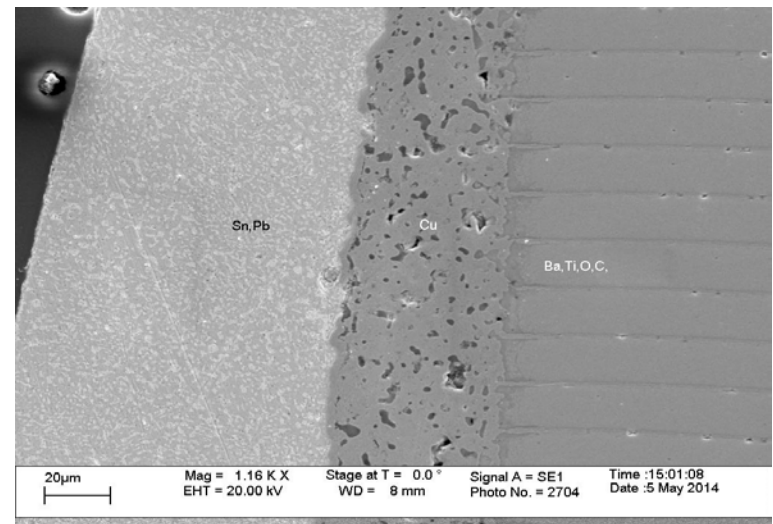
Procurement of Automotive EEE Parts Lesson Learned (2)

- Some AEC Q ceramic chip capacitors may be supplied with either “flexible termination” or “standard termination” at the discretion of the supplier.
- **Manufacturer decided to sell an equivalent part “better than” the one ordered**
- **Not just an issue for capacitors, potential for all part types**

Mfr “A” - Flexible termination



Mfr “C” - Standard termination



Lessons from Testing

- So far, all parts tested, passed datasheet limits as received (basic electricals)
- Capacitor testing showed need for a bake out after DWV to “reset” capacitance
- 0805 Capacitor DPA showed different termination materials
- Many PEM's had glass transition temperatures below 125C
- Baseline electricals for 0402 were established after mounting to reduce handling of small parts
- Datasheet for digital part gave a typical value for only one electrical parameter at high temperature and testing showed actuals were about 2x this “typical” value

General Lessons Learned

- Most AEC parts are non-hermetic but a few manufacturers provide hermetic automotive grade devices
- Device packaging is typically molded plastic, “Green Molding Compound”.
- Automotive and commercial AEC Q101 devices have implemented the use of copper bond wires instead of gold bond wires.
- Purchase costs of AEC and catalog COTS are around the same
- Pure tin finishes are allowed (possible tin whisker risk)
- Some or all manufacturing steps likely to occur in China

Conclusions

- So far, some issues have been found and some lessons learned but no “showstoppers”
- Automotive grade EEE parts are rated for automobile environment (in cabin or under hood) – not space! However, the underlying qualification system provides a strong foundation
- Overall, results so far are encouraging

BACK-UP

Automotive Electronics Council (AEC)

<http://www.aecouncil.com/>

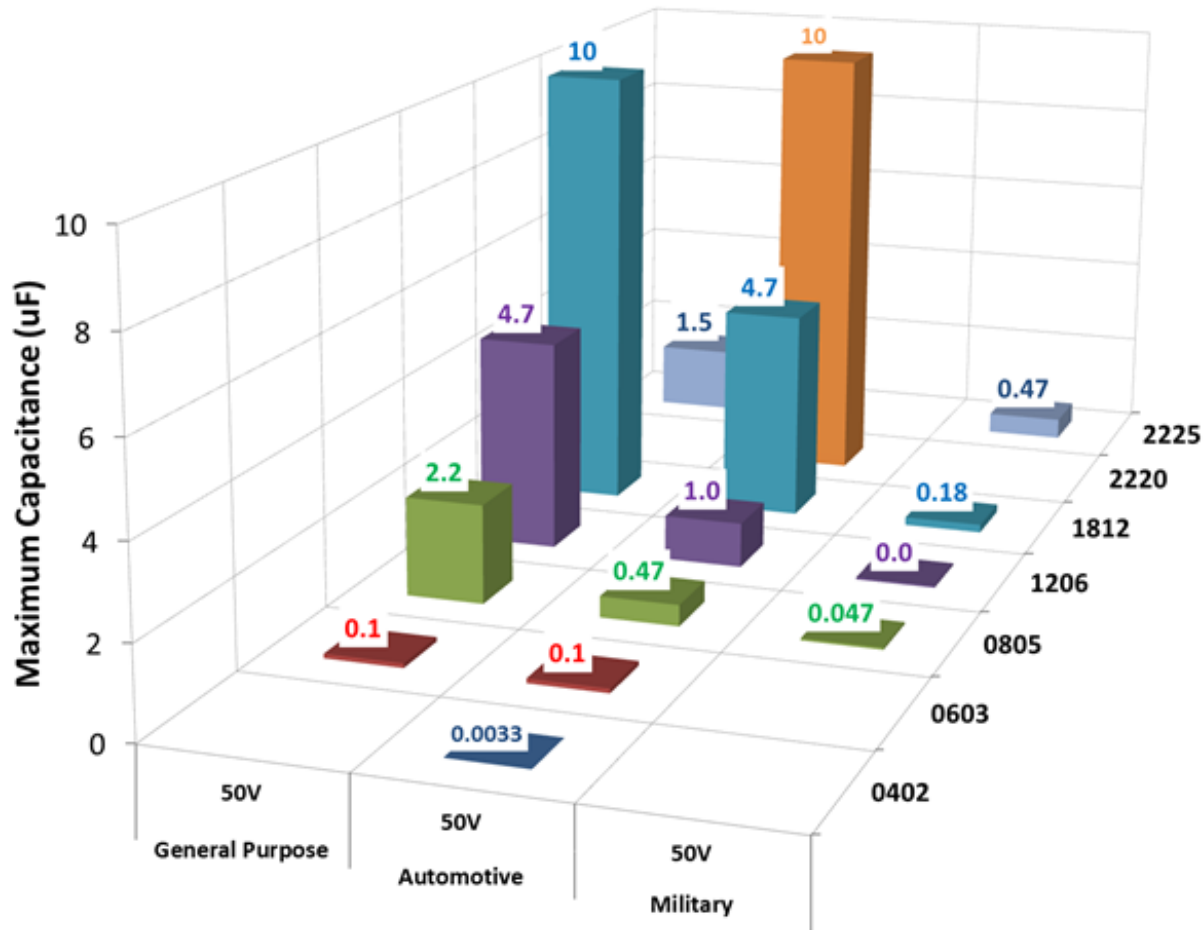
- Established early 1990s by Ford, GM, Chrysler
- Purpose to establish ***common EEE part-qualification and quality-system standards*** for use by major automotive electronics manufacturers
- Driven by desire to restore the attention given by EEE parts supplier which was declining due to the decreasing market share of automotive electronics
- Originally comprised of two committees
 - **AEC Component Technical Committee**
 - Quality Systems Committee ← **No Longer Active**

Beyond AEC Q –

What do SOME Automotive EEE Parts Customers Require?

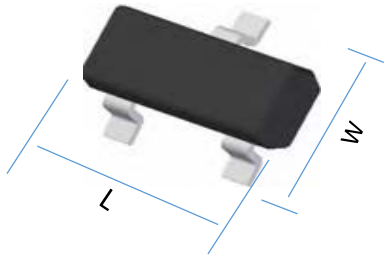
- Manufacturer should be ISO TS 16949 certified (or equivalent) for Quality Management Systems for Automotive Production
 - Third party audits
 - Full assessment typically every 3 years
 - Partial assessment typically every 1 year (optional every 6 months)
- Manufacturer should follow the Automotive Industry Action Group (AIAG) Production Part Approval Process (PPAP).
- Customer audits
 - May perform an Initial Audit before adding supplier to their approved vendors lists
 - Subsequent audits may only occur when “problems arise”
- Customer-specific requirements – SCDs for automotive grade “plus”
 - Unique qualification tests
 - Unique screening tests

Size Comparison 50V Ceramic Chip Capacitors



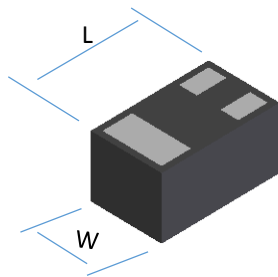
Package Examples for 2N2222 Bipolar Transistor

Automotive Grade



W = 2.5 mm/0.098 inch
 H = 1.1 mm/0.043 inch
 L = 3.0 mm/0.1181 inch

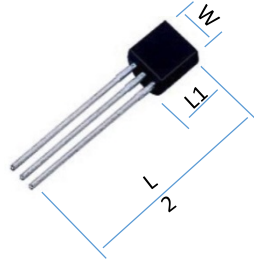
SOT-23



W = 0.65 mm/0.0255 inch
 H = 0.4 mm/0.0157 inch
 L = 1.05 mm/0.0413 inch

X2-DFN-1006-3

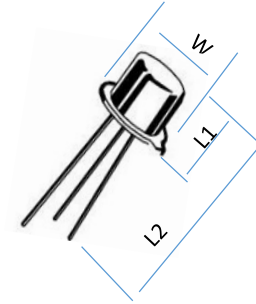
Commercial Grade



W = 5.20 mm/0.205 inch
 H = 4.19 mm/0.165 inch
 L1 = 5.33 mm/0.210 inch
 L2 = 17.02 mm/0.67 inch

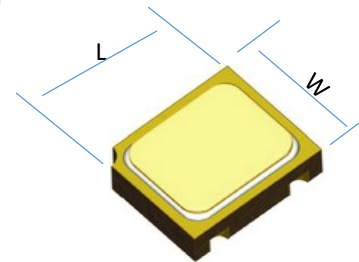
Plastic TO-92

Military/Space Grade



W = 5.84 mm/0.230 inch
 L1 = 5.33 mm/0.210 inch
 L2 = 24.384 mm/0.96 inch

Hermetic TO-18

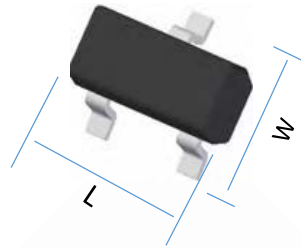


W = 5.84 mm/0.230 inch
 H = 5.33 mm/0.210 inch
 L = mm/ inch

Hermetic CerSOT – UB

Package Examples for Switching Diode

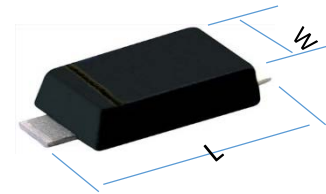
Automotive Grade



W = 2.5 mm/0.098 inch
H = 1.1 mm/0.043 inch
L = 3.0 mm/0.1181 inch

SOT-23

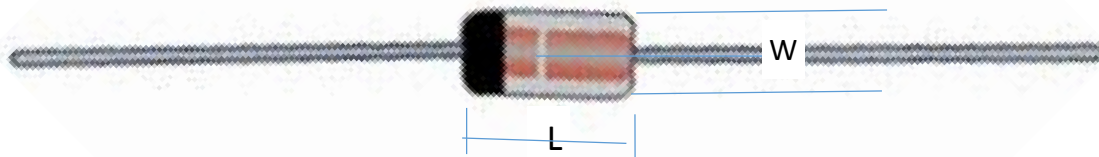
Commercial Grade



W = 0.152 mm/0.006 inch
H = 1.1 mm/0.043 inch
L = 3.0 mm/0.1181 inch

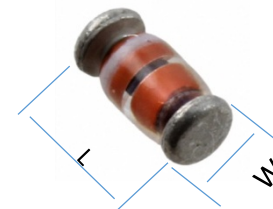
SOD-123

Military/Space Grade



W = 1.91 mm/0.075 inch
L = 4.57 mm/0.181 inch

DO-35

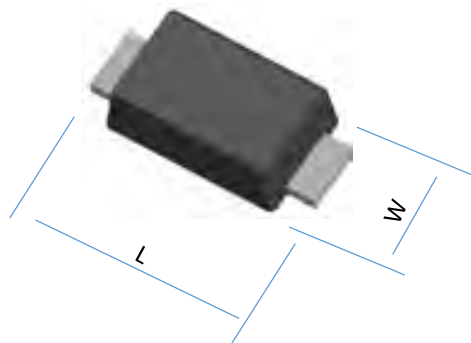


W = 1.70 mm/0.067 inch
L = 3.71 mm/0.146 inch

UR – surface mount

Package Examples for Schottky Barrier Diode

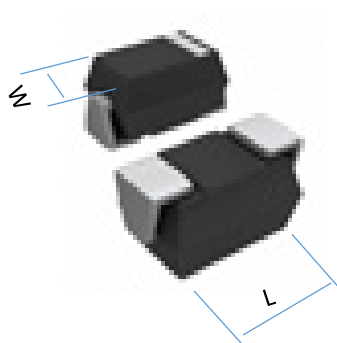
Automotive Grade



W = 1.91 mm/0.039 inch
H = 1 mm/0.076
L = 3.90 mm/0.1535 inch

Powerdi123

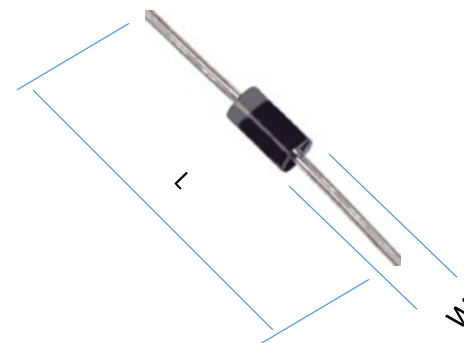
Commercial Grade



W = 2.84 mm/0.112 inch
H = 3.15 mm/0.124
L = 4.57 mm/0.18 inch

DO-214AC

Military/Space Grade



W = 1.91 mm/0.075 inch
L = 78.10 mm/3.075 inch

DO-41



W = 2.67 mm/0.105 inch
L = 5.21 mm/.205 inch

DO-213AB – surface mount

What do AEC Q Specifications contain?

AEC Q specifications are Qualification Requirements Only, Focused on:

- A One-Time INITIAL QUALIFICATION of a Device Family
 - Periodic Qualification Verification NOT REQUIRED
 - Guidance is given to define what constitutes a “Device Family”
 - Specifies # of lots, qualification tests to perform and sample sizes
 - “Generic Data” may be used provided relevance of data can be demonstrated (e.g., less than 2 years old for passives)
- Requirements for REQUALIFICATION
 - Provides recommendations for requalification tests in the event certain kinds of materials or process changes are made after initial qualification
- Requirements for process change notification to automotive customers (sub-system suppliers to automotive manufacturers)
- **THEY DO NOT PROHIBIT PURE TIN – Whisker mitigation recommended**

What do the AEC “Q” Specs **NOT** Provide?

- **No Qualifying Activity** to certify manufacturer meets qualification requirements
 - *Manufacturers “Self Certify” their compliance to AEC “Q”*
 - *Each User responsible to review the qualification data to verify compliance to AEC “Q”*
- Does Not Require Supplier Quality Audits
 - In practice, most EEE component manufacturers are certified to ISO TS 16949
 - Does Not Require SCREENING to remove infant mortality or quality defects
 - *Screening is at discretion of each manufacturer and as such is Not Standardized across the manufacturer base and may also be customer specific*
- Does Not Provide Standard Specifications nor Part Numbers for Procurement
 - Manufacturers choose their “automotive grade” designs and part numbers