Automotive Grade Electronic Parts for In-Space Applications

An Affordable and Effective Option?

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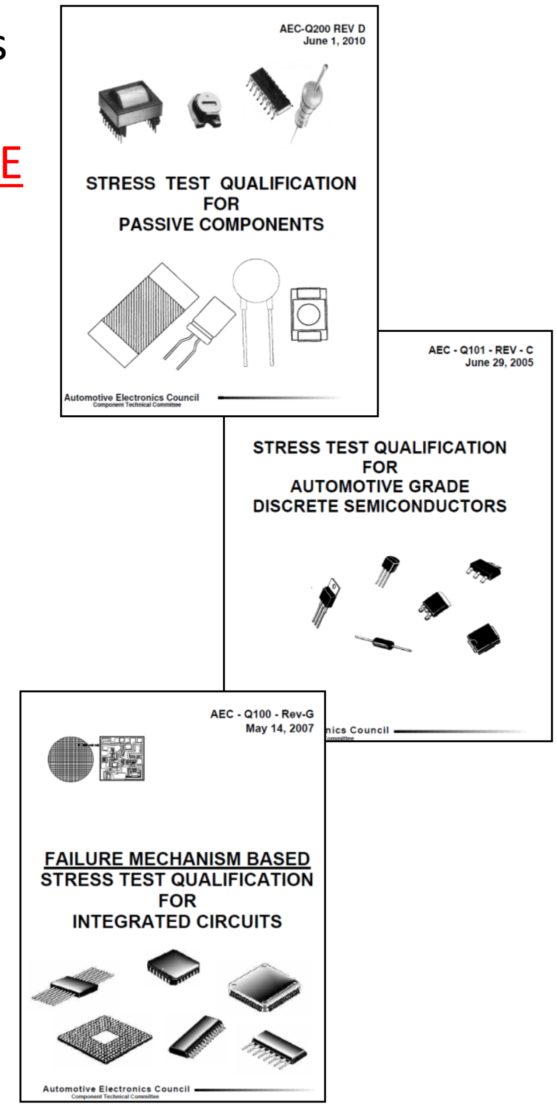
Acronyms

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" Are Directly Overseeing US Standards for Automotive Grade EEE Parts, But…

image by latestnewslink.com

AEC Component Technical Committee *Organizational Structure*

- Sustaining Members (Tier 1)
  - Governing body
  - Full voting privileges
- Technical Members (Tier 2)
  - Automotive market companies that make or use automotive electronic components
  - Full voting privileges
- Associate Members (Tier 3)
  - Any organization providing services or support to electronics industry
  - Limited voting privileges
- Guest Members
  - Other electronics market company or organization (e.g., medical, military)
  - No voting privileges

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

Sustaining Members of AEC

http://aecouncil.com/

MAGNA
MAGNA ELECTRONICS
Autoliv
JOHN DEERE
TRW
BOSE®
Continental
DENSO
Visteon®
Cummins®
DELPHI
HARMAN
HELLA
LEAR® CORPORATION
Valeo
GENTEX CORPORATION

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

Technical, Associate and Guest Members of AEC

http://aecouncil.com/

AEROSPACE Assuring Space Mission Success
ALTERA
AMRDEC
ANALOG DEVICES
ams
CIRRUS LOGIC
CYPRESS PERFORM
DfR Solutions reliability designed, reliability delivered
FAIRCHILD SEMICONDUCTOR

Launched by Motorola freescale semiconductor
FUJITSU
GLOBALFOUNDRIES
INDIUM CORPORATION
infineon
International IOR Rectifier
ISSI

The Capacitance Company KEMET CHARGED.
LATTICE SEMICONDUCTOR
Littelfuse
MXIC
maxim integrated
MICROCHIP
Micron
muRata Innovator in Electronics
NXP

ON
ON Semiconductor
Peregrine Semiconductor
PERICOM Enabling Serial Connectivity
RENESAS
SMIC
SPANSION
ST life.augmented
TDK

TEXAS INSTRUMENTS
tsmc
Tyco Electronics
VISHAY
winbond
XILINX

AEC Parts are Intended for Cars

Suitability for Space Use Depends on:

- Mission
- Risk Posture
- Commercial Options
- Matching Parts to Applications
- Cost vs Benefit
- Architecture Factors
- Sharing Lessons Learned

AND, of course – Part Performance

Microsoft® Clip Art

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)
- <u>They are cost competitive to catalog COTS</u>

Automotive Definitions

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- Tier 1 Supplier – Manufacturer to the vehicle assemblers who are responsible for delivery of the finished assembly, product development and continued technology renewal.
- Tier 2 Supplier – Producer of parts providing value-added to minor sub-assembly.
- Tier 3 Supplier – Supplier of engineered materials and special services such as rolls of sheet steel, bars, and heat treating surface treatments.
- Tier 4 Supplier – Supplier of basic raw materials to higher Tier suppliers.

Automotive Parts are Made for Automobiles!

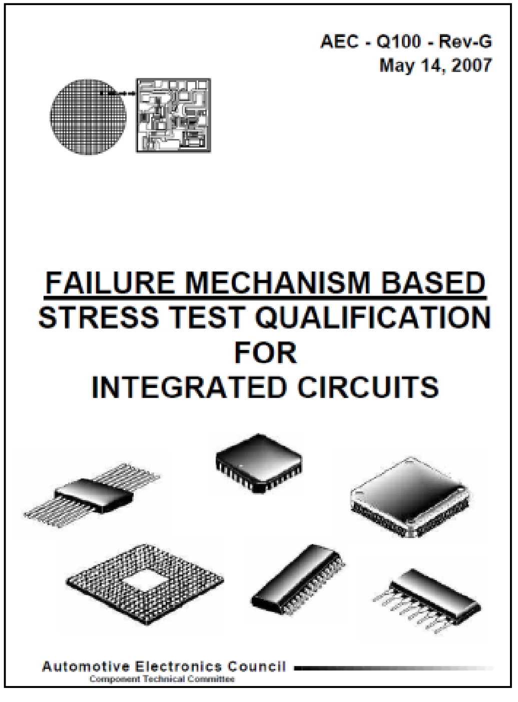
Automotive Electronic Parts

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

AEC Q-100
Microcircuits

AEC Q-101
Discrete Semiconductors

AEC Q-200
Passives



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

Qualification: Automotive vs Military

- Automotive Qualification testing consists of:
  - Basic Electricals 100%
  - Qualification electrical and environmental tests typically performed on sample sizes ranging from 5 to 77 devices depending on test method.
  - Testing required for multiple (2 or 3), non-consecutive lots
  - Extensive testing including various life tests, some accelerated
  - ESD testing uses human body model, machine model, and charged device model
  - **Can utilize generic data**
  - **Includes valid and valuable tests not required for MIL qualification**
- Qualification for Military product consists of:
  - Electrical and environmental screening 100%
  - Conformance inspection done on sample basis ranging from 22 to 116 devices.
  - 1000 hour life tests
  - One qualification lot but no generic data
  - ESD testing utilizes human body model only

Screening: Automotive vs Military

- Automotive screening could consist of:
  - Basic Electricals 100%
  - Part specific electrical and environmental tests on a sample basis
  - **Customer-specific flows for major (big $) customers** (not typically the aerospace customer)
- Screening for Military product typically consists of:
  - Screening on every inspection lot
  - Electricals done 100%
  - Burn-in and life test
  - Environmental testing done 100%
  - Exception is 'JAN' and non - Established Reliability (non-ER) grade devices which are similar to automotive.

What is ISO TS 16949?

TECHNICAL SPECIFICATION

ISO/TS 16949

Third edition
2009-06-15

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

- 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

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. <u>Records of Material/Performance Tests</u>
  8. Initial Process Studies
  9. Qualified Laboratory Documentation
  10. Sample Production Parts
  11. <u>Customer-specific requirements</u>
  12. Parts Submission Warrant (PSW)

Production Part Approval Process (PPAP)

- PPAP Levels 1 to 5
  - End user determines required supplier PPAP level
- Typical PPAP level used is Level 3

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.

An Important Point of Reference

- According to: *http://cars.lovetoknow.com › Lifestyle › Cars › About Cars,* the average annual mileage driven per car in the US is 13,476
- If the average speed is 20 miles per hour (conservative) this means ~ 680 hours/year
- Average age of an automobile in the US is 11.4 years, totally a performance experience of 7752 hours by this estimation
- ***Spacecraft systems working 24/7 operate for 8766 hours/year***
- Admittedly, some auto systems do operate 24/7 but they are not safety critical or performance critical.
  - The security system operates 24/7 and is could be considered critical but the car is still perfectly drivable with it broken

NEPP Evaluation of Automotive EEE Parts
The Plan

- Procure sample automotive grade EEE parts
  - Procure via standard distribution (e.g., Mouser, Digikey, etc.)
  - Parts advertised by supplier to meet “AEC Q” requirements
- Assorted Automotive Grade EEE Parts selected for evaluation:
  - 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 cheap 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

Capacitors

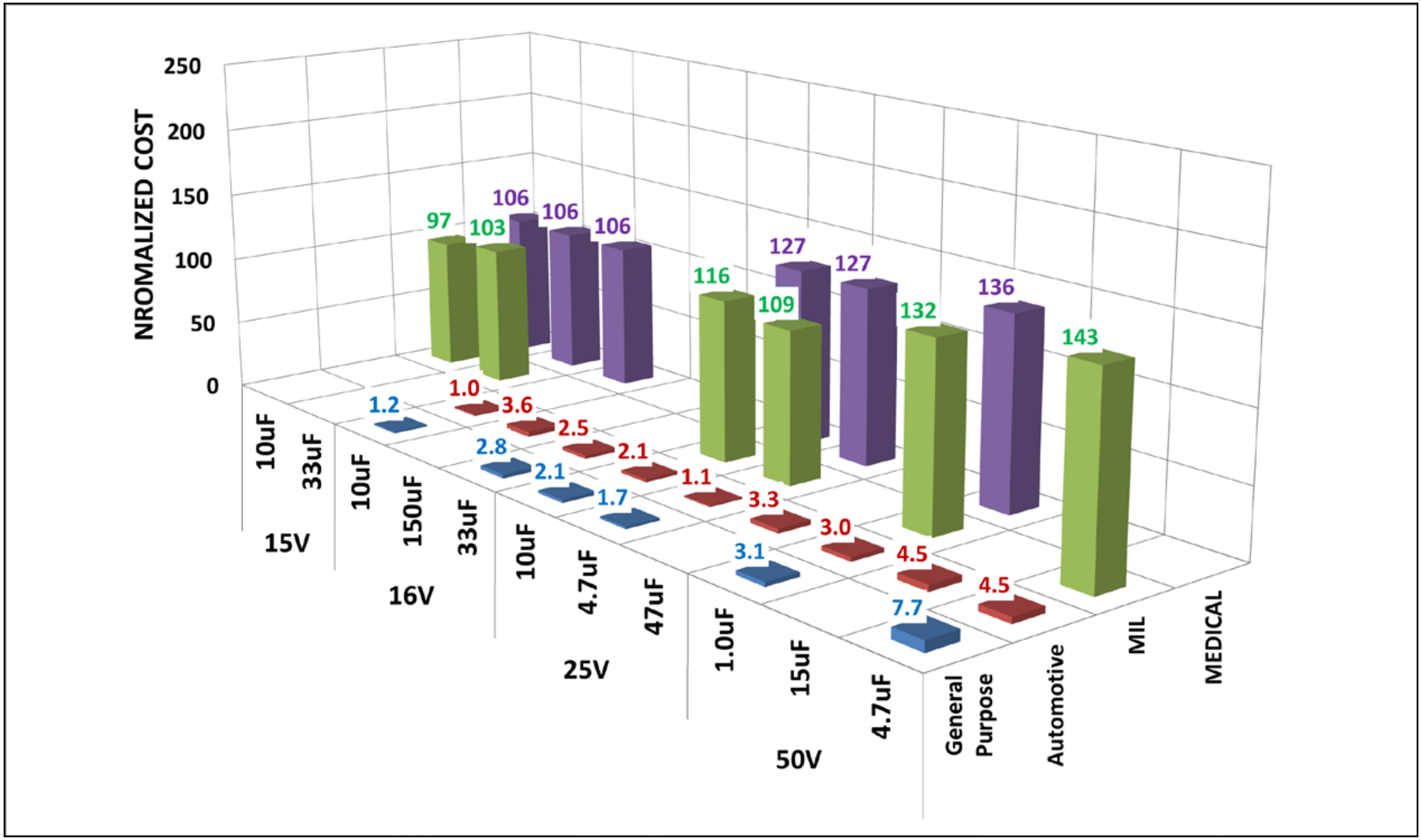
Tantalum Chip Capacitors

AVX Catalog S-TL0M714-C

http://www.bico.net.cn.img.800cdn.com/en/UploadFiles/200651510577614.jpg

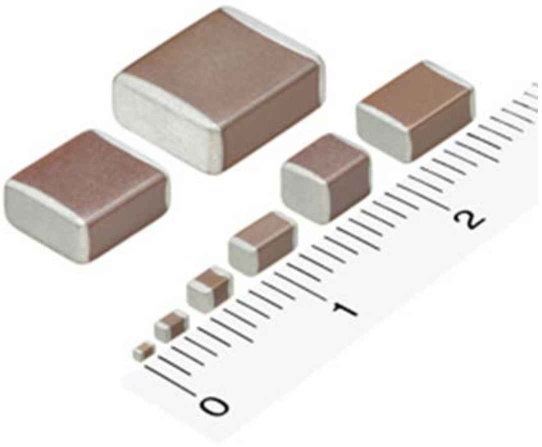
Tantalum Chip Capacitors

Normalized Cost Comparison for Selected Ratings



Ceramic Chip Caps

http://www.global.tdk.com/news_center/press/img/20140424_01.jpg



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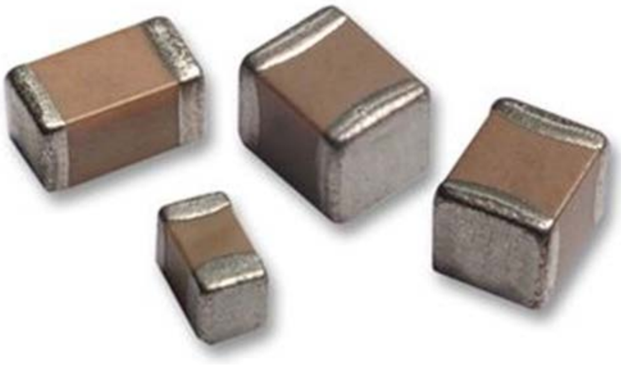
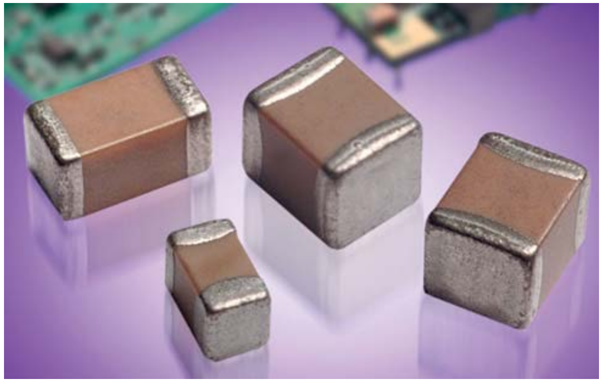
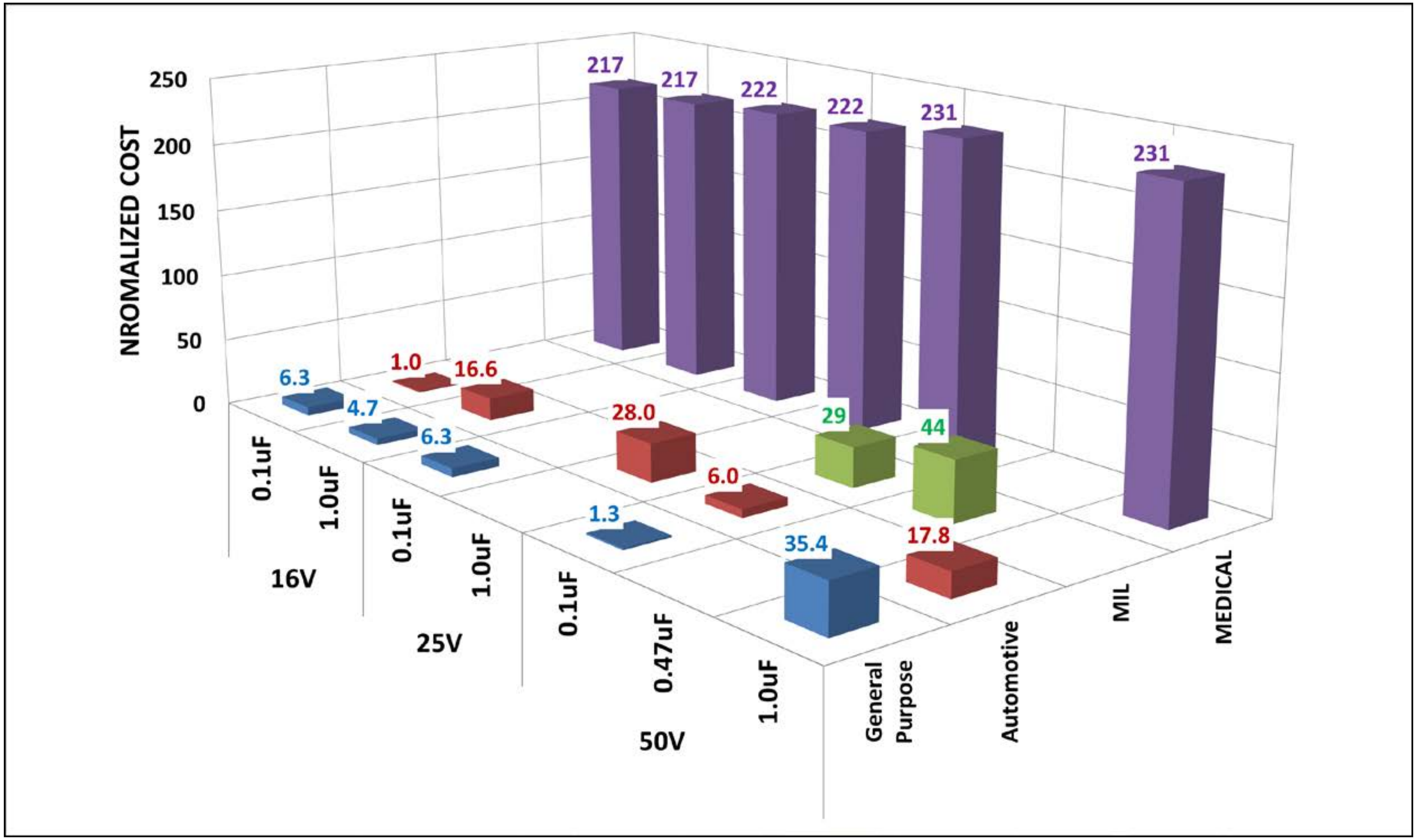


AVX Catalog S-MLCC0414-C

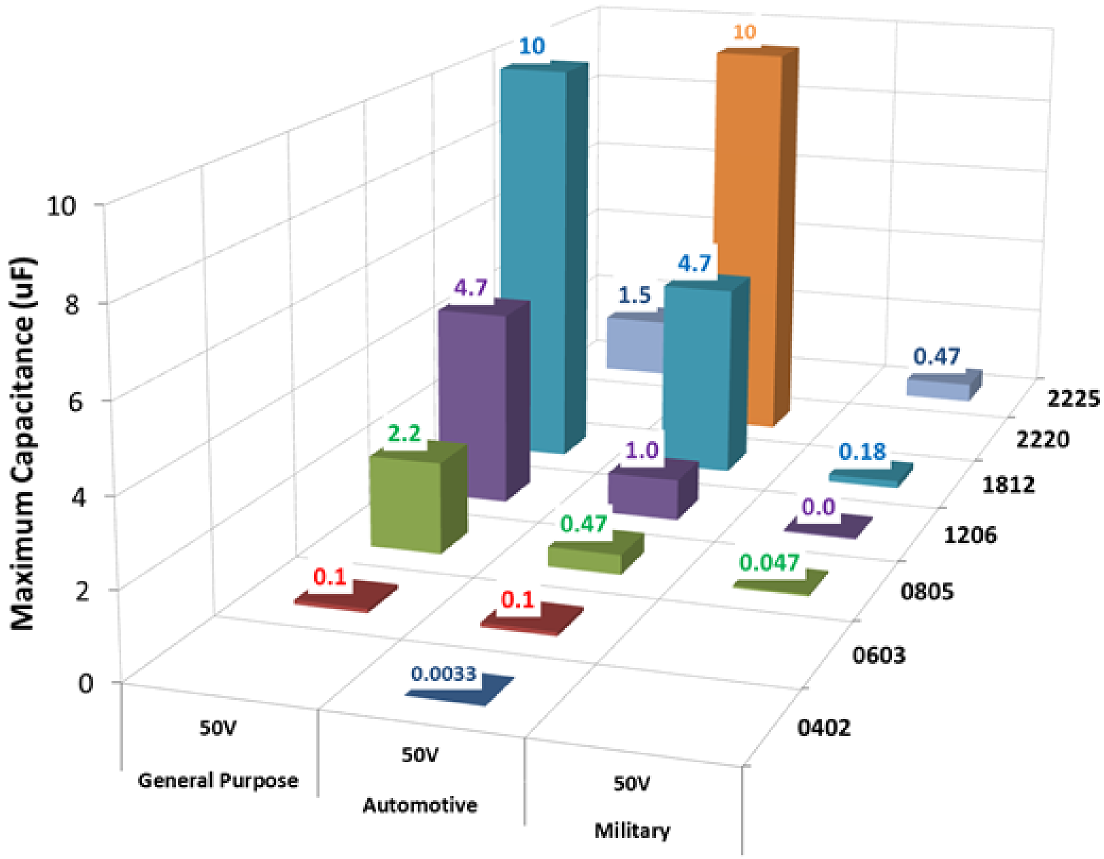


Ceramic Chip Capacitors

Normalized Cost Comparison for Selected Ratings



Size Comparison 50V Ceramic Chip Capacitors



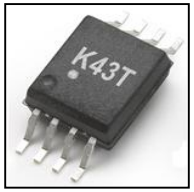
Discrete Semiconductors

Package Examples for Schottky Diodes and Optocouplers

Automotive Grade

Medical Grade

Commercial/MIL /Space



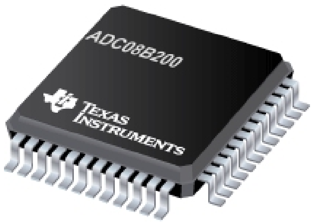
General Comments - Discretes

- Having two or more manufacturers of the same AEC Q101 part number does not translate to a form, fit, and function drop in replacement.
- AEC qualified discrete semiconductors sources NOT MIL-PRF-19500 QPL
- Cost comparison did not factor in the additional costs due to upscreening devices to meet program requirements.
- For a lot of 100 pcs, upscreening of medium complexity auto grade parts to mil grade could cost \$15k-30k (which amounts to \$150-\$300 per unit). This was not factored into the cost comparison.

Microcircuits

General Comments - Microcircuits

- AEC qualified “DC/DC Converters” aren’t MIL-PRF-38534 companies
  - Companies are MIL-PRF-38535
- Cost Comparison was done without factoring in upscreening
- Radiation Assurance NOT included
- In the limited samples taken
  - AEC generally costs around the same as COTS
  - Very difficult to find equivalent MIL and medical grade level of AEC components



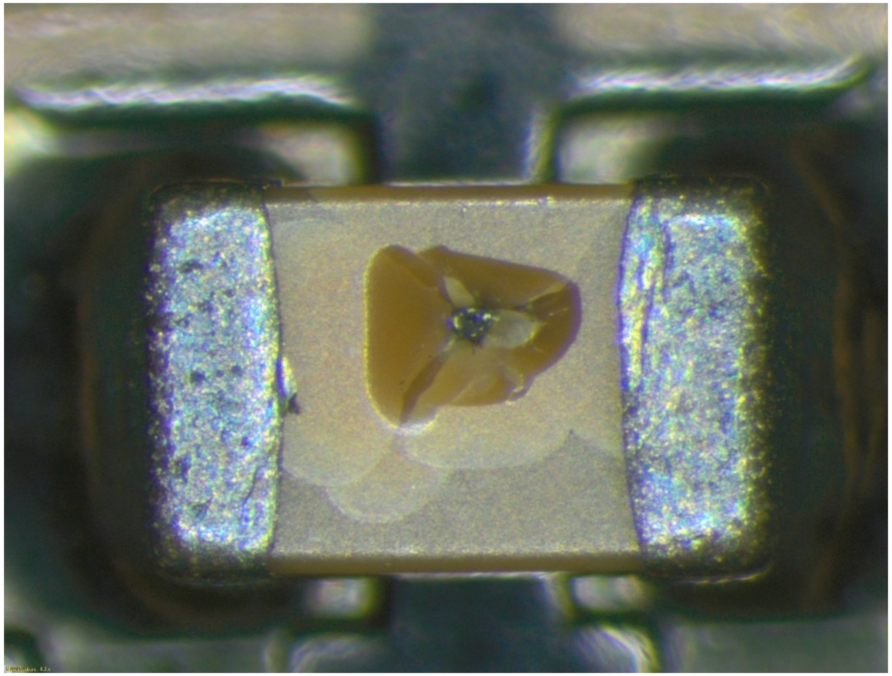
- PURE TIN FINISHES
- Some or all manufacturing steps likely to occur in China

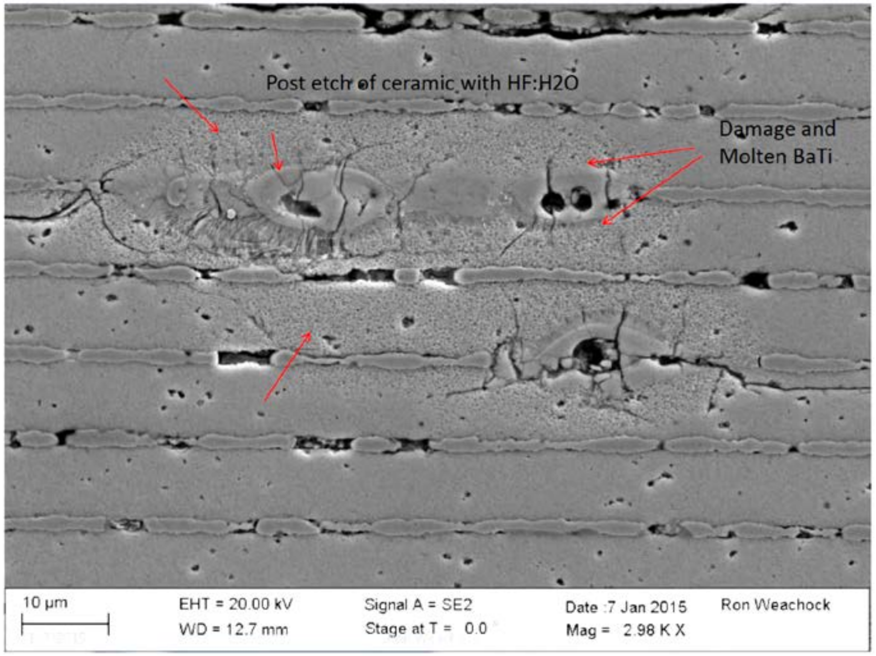
Testing Summary: NEPP Evaluation Automotive Parts

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

Commodity	Test	Status	Comments
Ceramic Capacitors 3 Different Mfrs BME, 0805, 0.47uF, 50V	Construction Analysis	Complete	• ***At their own discretion* a manufacturer supplied devices made with "flexible termination"**
	Initial Parametric Measurements	Complete	• No Failures • *DWV known to produce negative cap shift* • *Mfrs recommend bake-out to restore cap*
	Life Test (2x Vrated, 125°C)	> 7000 Hrs Complete (Progressing to 10k hours)	• *1 lot exhibits 6 life test failures (120pc) up to 7500 hrs* • *2 fail @ 3100 hrs; 3 fail @ 4700 hrs; 1 fail @ 6200 hrs* • 2 lots exhibit no life test failures up to ~7500 hrs
Integrated Circuits 2 Different Mfrs 1 digital IC (Diff Bus Driver); 1 linear IC (Comparator)	Construction Analysis	In Process	• *FOD on Terminals "As-Received" (Linear IC)* • Tg measurements complete • CSAM complete for digital IC • C/A to be performed at end of test
	Initial Parametric Measurements	In Process	• No Failures for digital IC • Linear IC to be tested 04/15
	Burn-In & Life Test	In Process	• All digital ICs failed during burn-in. Appears to be a power consumption issue at burn-in temperature. Investigation Pending
Discrete Semiconductors 1 Bipolar transistor (dual transistor) 1 Switching diode 1 Transient Voltage Suppressor 1 Schottky Diode	Construction Analysis	In Process	• Tg measurements complete
	Initial Parametric Measurements	In Process	• No Failures for bipolar transistor • Switching diode to be tested 07/15
	Burn-In & Life Test	In Process Began 03/15	• Bipolar transistor - 1000 hours of life test completed (20 pcs), *(1 failure under investigation at 1000 hours)** • Bipolar transistor – life test continuing on to 2000 hours • CA to be performed at end of test • Switching diode electrical and life tentatively scheduled to start testing late 07/15 due to parts ordering issue

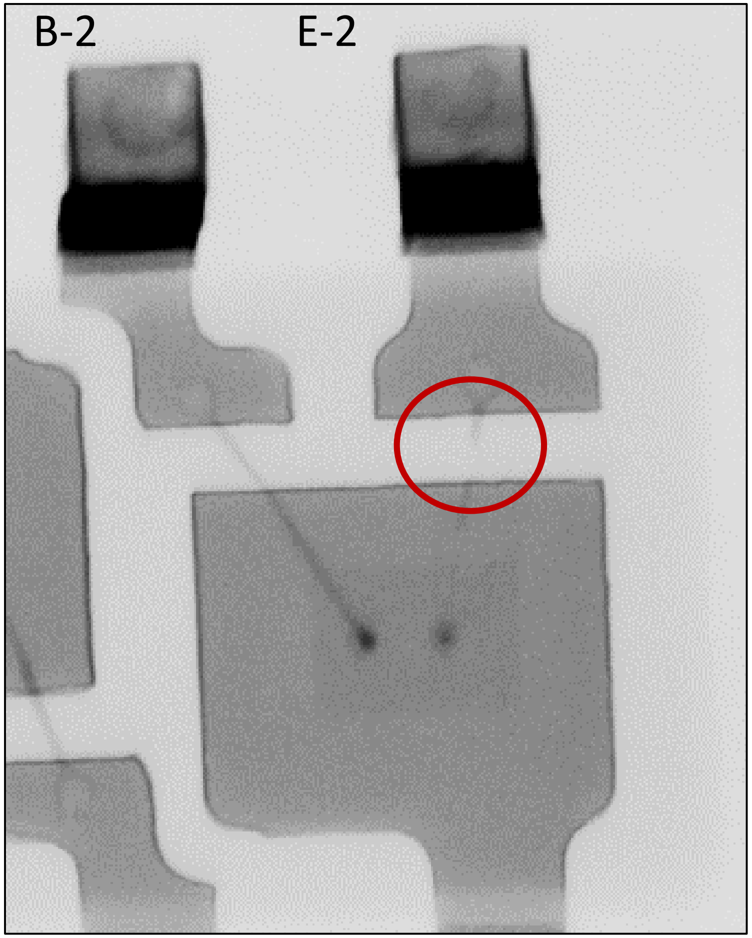
Example of Catastrophic Life Test Failure
Mfr "A" Ceramic Chip Capacitor - Short Circuit



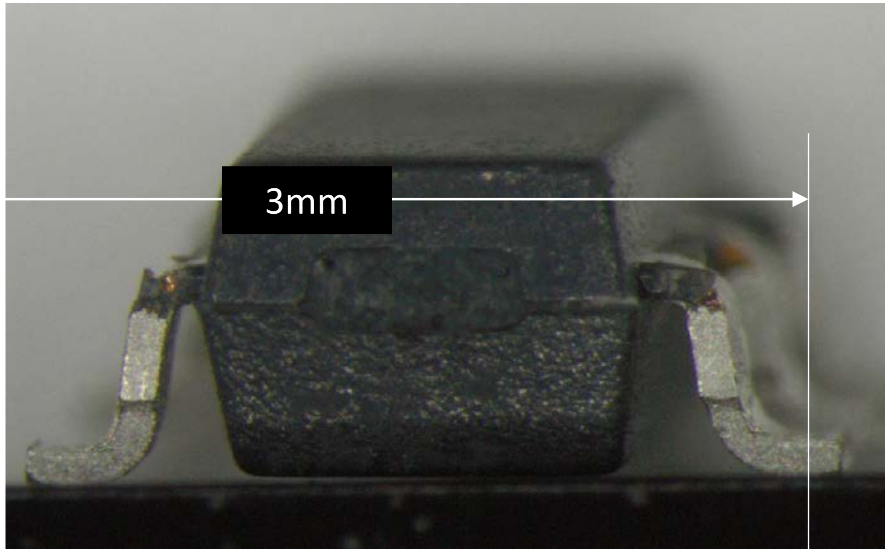


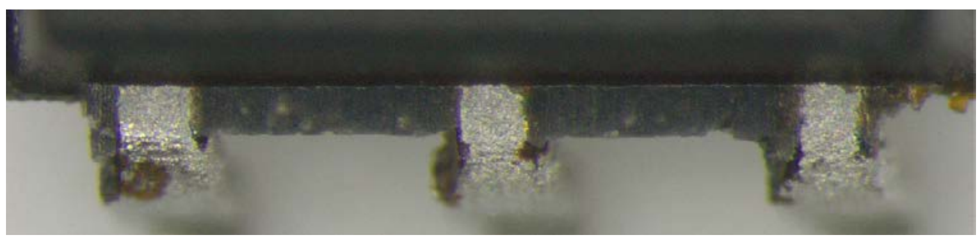
Bipolar Transistor Failure Initial Analysis Results

- X-ray Top View Showing Fused Emitter 2 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

Lessons Learned

An Important Lesson Realized

- Automotive “bus” is nominally 12 volt (~14 volts actual)
- Traditional spacecraft bus is 28volts
  - But 40, 70, 120 volts have been used
- This limits applicability of some automotive parts for space applications
- Is there a typical bus voltage or voltages for smallsats and cubesats?
  - Can adequate derating be achieved with automotive parts?
  - Maybe and maybe – still evolving

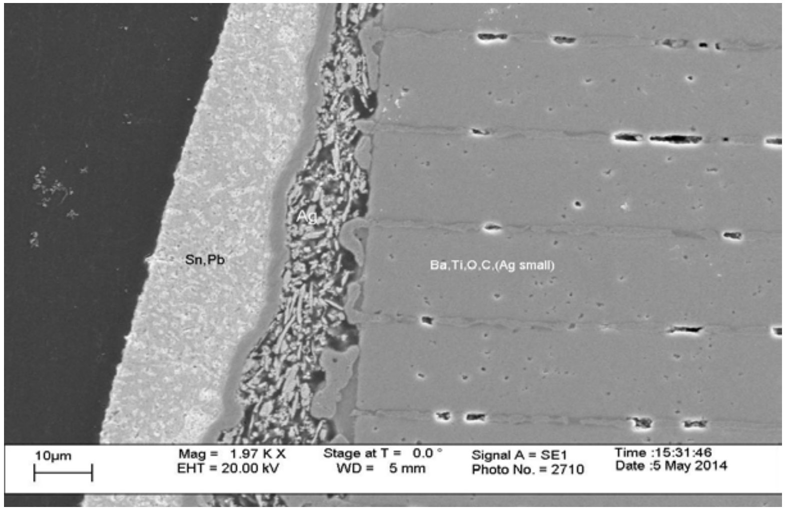
Procurement of Automotive EEE Parts Lessons Learned (1)

- Anybody can buy catalog “AEC Q” parts via authorized distributors
  - Many part types can be purchased in small batches or min orders around 100 pcs
  - Discounts for large orders
  - Manufacturers require large minimum buys, as do some major 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 paper may not have same details as manufacturer’s**

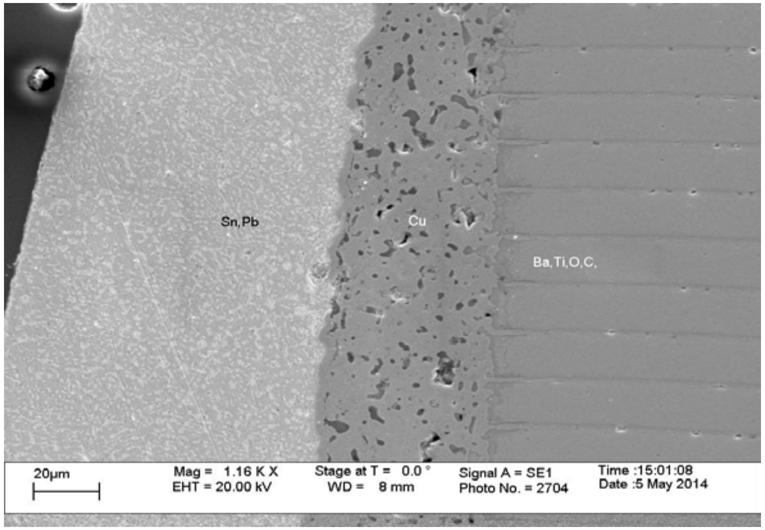
Procurement of Automotive EEE Parts Lesson Learned (2)

- 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



General Lessons Learned

- Most AEC parts are non-hermetic but a few manufacturers provide hermetic automotive grade devices
- A few manufacturers design for a 25 year life, other suppliers design for a shorter life.
- 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.
- Very difficult to find MIL and medical grade of AEC components
- Cost of AEC and COTS are around the same
- Some or all manufacturing steps likely to occur in China

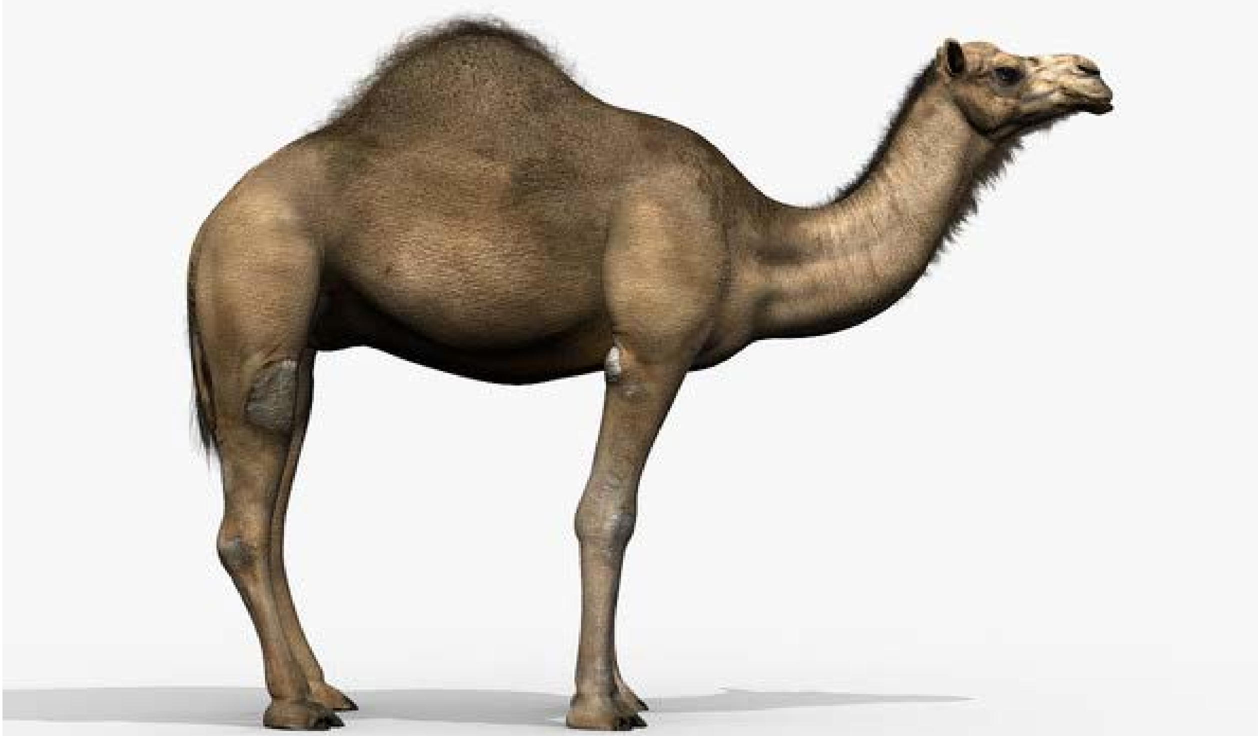
Lessons from Testing

- So far, all parts tested, passed datasheet testing (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

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 structure provides a strong foundation
- Not all automotive grade EEE discrete semiconductor parts are constructed to the same reliability levels:
- HOWEVER, 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**

Automotive Applications – Influential Factor Harsh Environment

- Automobile
  - Extended warranty = 4000 hrs operation typical
  - Typical use environments include frequent exposure to:
    - Severe shock and vibration – rough roads, potholes, curbs etc.
    - Wide temperature extremes – Alaska in winter, Death Valley in summer, under hood anywhere at any time,
    - Wide humidity extremes – desert southwest and southeast US,
  - Mitigations include:
    - Plastic encapsulated EEE parts in solid encapsulated modules - no freedom of movement under shock or vibe
    - Auto parts in different grades based on rated ambient operating temperature range:
      - Grade 0: -40°C to +150°C
      - Grade 1: -40°C to +125°C
      - Grade 2: -40°C to +105°C
      - Grade 3: -40°C to +85°C
      - Grade 4: 0°C to +70°C
- Traditional Space Vehicles
  - Operational lives range from 3 months to >15 years (2000 to > 130,000 hrs)
  - Launch vehicles minutes to a few days
  - Severe shock and vibe during launch
  - Typically less severe during deployment of doors, covers, solar panels etc;
  - Extreme cold and heat for short and long space missions
- Cubesats
  - What are OTS kits using?
  - What are implications?
  - We found it difficult to identify OTS auto power converters

Part Submission Warrant

DaimlerChrysler Ford GM

Part Submission Warrant

Part Name | Cust. Part Number
Shown on Drawing No. | Org. Part Number
Engineering Change Level | Dated
Additional Engineering Changes | Dated
Safety and/or Government Regulation ☐ Yes ☐ No | Purchase Order No. | Weight (kg)
Checking Aid No. | Checking Aid Engineering Change Level | Dated

ORGANIZATION MANUFACTURING INFORMATION

Organization Name & Supplier/Vendor Code

Street Address

City Region Postal Code Country

CUSTOMER SUBMITTAL INFORMATION

Customer Name/Division

Buyer/Buyer Code

Application

MATERIALS REPORTING

Has customer-required Substances of Concern information been reported? ☐ Yes ☐ No ☐ n/a

Submitted by IMDS or other customer format:

Are polymeric parts identified with appropriate ISO marking codes? ☐ Yes ☐ No ☐ n/a

REASON FOR SUBMISSION (Check at least one)

- ☐ Initial Submission
- ☐ Engineering Change(s)
- ☐ Tooling: Transfer, Replacement, Refurbishment, or additional
- ☐ Correction of Discrepancy
- ☐ Tooling Inactive > than 1 year
- ☐ Change to Optional Construction or Material
- ☐ Supplier or Material Source Change
- ☐ Change in Part Processing
- ☐ Parts Produced at Additional Location
- ☐ Other - please specify below

REQUESTED SUBMISSION LEVEL (Check one)

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

SUBMISSION RESULTS

The results for ☐ dimensional measurements ☐ material and functional tests ☐ appearance criteria ☐ statistical process package

These results meet all drawing and specification requirements: ☐ Yes ☐ No (If "NO" - Explanation Required)

Mold / Cavity / Production Process

DECLARATION

I hereby affirm that the samples represented by this warrant are representative of our parts which were made by a process that meets all Production Part Approval Process Manual 4th Edition Requirements. I further affirm that these samples were produced at the production rate of / hours.

I also certify that documented evidence of such compliance is on file and available for review. I have noted any deviations from the declaration below.

EXPLANATION/COMMENTS:

Is each Customer Tool properly tagged and numbered? ☐ Yes ☐ No ☐ n/a

Organization Authorized Signature | Date

Print Name | Phone No. | Fax No.

Title | E-mail

FOR CUSTOMER USE ONLY (IF APPLICABLE)

Part Warrant Disposition: ☐ Approved ☐ Rejected ☐ Other

Customer Signature | Date

Print Name | Customer Tracking Number (optional)

March 2006 **CFG-1001**

Automotive Part Grades and Temperatures

Automotive	Temperature	AEC 100	AEC 101 Discrete Semiconductors		AEC 200
Grade	Range	Microcircuits	Discretes except LEDs	LEDs	Passives
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 Q100 Qualification Sample Size

AEC - Q101 - REV - C
June 29, 2005

Automotive Electronics Council
Component Technical Committee

TABLE 2 - QUALIFICATION TEST DEFINITIONS

#	Stress	Abrv	Data type	Note	Sample Size per lot	# of lots	Accept on # failed	Reference (current revision)	Additional Requirements
1	Pre- and Post-Stress Electrical Test	TEST	1	NG	All qualification parts tested per the requirements of the appropriate device specification.		0	User specification or supplier's standard specification	Test is performed as specified in the applicable stress reference at room temperature.
2	Pre-conditioning	PC	1	GS	SMD qualification parts for TC, AC,H^3TRB & IOL/PTC		0	JESD22 A-113	Performed on surface mount devices (SMDs) prior to TC, AC, H^3TRB & IOL/PTC stresses only. Use A113 Sensitivity Level 1. TEST before and after PC. Any replacement of parts must be reported.
3	External Visual	EV	1	NG	All qualification parts submitted for testing		0	JESD22 B-101	Inspect device construction, marking and workmanship.
4	Parametric Verification	PV	1	N	25	3 Note A	0	Individual AEC user specification	Test all parameters according to user specification over the device temperature range to insure specification compliance.
5	High Temperature Reverse Bias	HTRB	1	DGUV P	77	1 Note B	0	JESD22 A-108	1000 hours at junction temperature T_J = 150°C, or specified T_J(max) rating, with device reverse biased to 80% of maximum breakdown voltage specification. The ambient temperature T_A is to be adjusted to compensate for current leakage. Can reduce duration to 500 hours through increasing T_J by 25°C, adjusting T_A to compensate for current leakage. TEST before and after HTRB as a minimum.
6	High Temperature Gate Bias	HTGB	1	DGMU P	77	1 Note B	0	JESD22 A-108	1000 hours at junction temperature T_J = 150°C, or specified T_J(max) rating, with gate biased at 100% of maximum gate voltage rating indicated in the detail specification with device biased OFF. The ambient temperature T_A is to be adjusted to compensate for current leakage. Can reduce duration to 500 hours through increasing T_J by 25°C, adjusting T_A to compensate for current leakage. TEST before and after HTGB as a minimum.

Page 10 of 25

AEC Q101 Qualification Sample Size

TABLE 2 - QUALIFICATION TEST DEFINITIONS

#	Stress	Abrv	Data type	Note	Sample Size per lot	# of lots	Accept on # failed	Reference (current revision)	Additional Requirements
7	Temperature Cycling	TC	1	DGU	77	1 Note B	0	JESD22 A-104	1000 cycles (T_A = minimum range of -55°C to maximum rated junction temperature, not to exceed 150°C). Can reduce duration to 400 cycles using T_A (max) = 25°C over device maximum rated junction temperature. TEST before and after TC as a minimum.
8	Autoclave	AC	1	CDG U	77	1 Note B	0	JESD22 A-102	96 hours, T_A = 121°C, RH = 100%, 15psig, TEST before and after AC.
9	High Humidity High Temp. Reverse Bias	H^3TRB	1	DGU V	77	1 Note B	0	JESD22 A-101	1000 hours at T_A = 85°C/85% RH with device reverse biased at 80% of rated breakdown voltage up to a maximum of 100V or limit of chamber. TEST before and after H3TRB as a minimum.
9 alt	Highly Accelerated Stress Test	HAST	1	CDG UV	77	1 Note B	0	JESD22 A-110	96 hours at T_A=130°C/85%RH with device reverse bias at 80% of rated voltage up to a voltage above which arcing in the chamber will likely occur (typically 42V). TEST before and after 96 hours HAST.
10	Intermittent Operational Life	IOL	1	DGTU WP	77	1 Note B	0	MIL-STD-750 Method 1037	Tested per duration indicated in Timing Requirements table on Page 13. T_A=25°C. Devices powered to insure $\Delta T_J \geq 100$°C (not to exceed absolute maximum ratings). TEST before and after IOL as a minimum.
10 alt	Power and Temperature Cycle	PTC	1	DGTU W	77	1 Note B	0	JESD22 A-105	Perform PTC if $\Delta T_J \geq 100$°C cannot be achieved with IOL. Tested per duration indicated for Timing Requirements in Table 2A. Devices powered and chamber cycled to insure $\Delta T_J \geq 100$°C (not to exceed absolute maximum ratings). TEST before and after PTC as a minimum.

AEC Q101 Qualification Sample Size

AEC - Q101 - REV - C
June 29, 2005

Automotive Electronics Council
Component Technical Committee

TABLE 2 - QUALIFICATION TEST DEFINITIONS									
#	Stress	Abrv	Data type	Note	Sample Size per lot	# of lots	Accept on # failed	Reference (current revision)	Additional Requirements
11	ESD Characterization	ESD	1 (HBM, MM) 2 (CDM)	D	30 ea CDM/ HBM/MM	1	0	AEC Q101-001, 002 and 005	Supplier must perform at least two of the referenced ESD models through the end of 2005. CDM will be required as one of the two selected models as of 2006. For CDM, small packages may not be able to hold enough charge to meet the specified discharge voltage. For these packages, perform the test once and, if there is insufficient charge, the supplier must instead perform HBM and MM. The supplier must document that the package could not hold sufficient charge to perform the test. See attached procedure for details on how to perform the test. TEST before and after ESD.
12	D.P.A.	DPA	1	DG	2	1 Note B	0	AEC-Q101-004 Section 4	Random sample of devices that have successfully completed H^3TRB or HAST, and TC.
13	Physical Dimension	PD	2	NG	30	1	0	JESD22 B-100	Verify physical dimensions to the applicable user device packaging specification for dimensions and tolerances.
14	Terminal Strength	TS	2	DGL	30	1	0	MIL-STD-750 Method 2036	Evaluate lead integrity of leaded devices only.
15	Resistance to Solvents	RTS	2	DG	30	1	0	JESD22 B-107	Verify marking permanency. (Not required for laser etched parts or parts with no marking.)
16	Constant Acceleration	CA	2	DGH (1)	30	1 Note B	0	MIL-STD-750 Method 2006	Y1 plane only, 15K g-force. TEST before and after CA.
17	Vibration Variable Frequency	VVF	2	DGH (2)	Items 16 through 19 are sequential tests for hermetic packages. (See note H on Legend page.)			JESD22 B-103	Use a constant displacement of 0.06 inches (double amplitude) over the range of 20Hz to 100 Hz and a 50g constant peak acceleration over the range of 100 Hz to 2 KHz. TEST before and after VVF.
18	Mechanical Shock	MS	2	DGH (3)			0	JESD22 B-104	1500 g's for 0.5mS, 5 blows, 3 orientations. TEST before and after MS.
19	Hermeticity	HER	2	DGH (4)			0	JESD22 A-109	Fine and Gross leak test per individual user specification.

AEC Q101 Qualification Sample Size

AEC - Q101 - REV - C
June 29, 2005

Automotive Electronics Council
Component Technical Committee

TABLE 2 - QUALIFICATION TEST DEFINITIONS									
#	Stress	Abrv	Data type	Note	Sample Size per lot	# of lots	Accept on # failed	Reference (current revision)	Additional Requirements
20	Resistance to Solder Heat	RSH	2	DG	30	1	0	JESD22 B-106	TEST before and after RSH. SMD devices shall be fully submerged during test unless justified by the supplier and agreed to by the user (e.g., submerge SOT223, not D2PAK).
21	Solderability	SD	2	DG	10	1 Note B	0	J-STD-002	Magnification 50x, Reference solder conditions in Table 2B. Test method A for through-hole, both B test methods and test method D for SMD.
22	Thermal Resistance	TR	3	DG	10 ea, pre & post change	1	0	JESD24-3, 24-4, 24-6 as appropriate	Measure TR to assure specification compliance and provide process change comparison data.
23	Wire Bond Strength	WBS	3	DGE	10 bonds from min of 5 devices	1	0	MIL-STD-750 Method 2037	Pre & Post process change comparison to evaluate process change robustness.
24	Bond Shear	BS	3	DGE	10 bonds from min of 5 devices	1	0	AEC-Q101-003	See attached procedure for details on acceptance criteria and how to perform the test.
25	Die Shear	DS	3	DG	5	1	0	MIL-STD-750 Method 2017	Pre & Post process change comparison to evaluate process change robustness.
26	Unclamped Inductive Switching	UIS	3	D	5	1	0	AEC-Q101-004 Section 2	Pre & Post process change comparison to evaluate process change robustness (Power MOS and internally clamped IGBTs only).
27	Dielectric Integrity	DI	3	DM	5	1	0	AEC-Q101-004 Section 3	Pre & Post process change comparison to evaluate process change robustness. All parts must exceed gate breakdown voltage minimum (Power MOS & IGBT only).

All electrical testing before and after the qualification stresses (including pre-conditioning) are performed to the limits detailed in the individual user specification at room temperature only. For generic qualifications, the supplier's standard specification limits at room temperature may be used.

Page 13 of 25

AEC Q101 Qualification Sample Size

LEGEND FOR TABLE 2

Notes:
- A For parametric verification data, sometimes circumstances may necessitate the acceptance of only one lot by the user. Should a subsequent user decide to use a previous user's qualification approval, it will be the subsequent user's responsibility to verify an acceptable number of lots were used.
- B Where generic (family) data is provided in lieu of component specific data, 3 lots are required.
- C Not applicable for LED's, phototransistors, and other optical devices.
- D Destructive test, devices are not to be reused for qualification or production.
- E Ensure that each size wire is represented in the sample size.
- G Generic data allowed. See Section 2.3.
- H Required for hermetic packaged devices only. Items 16 through 19 are performed as a sequential test to evaluate mechanical integrity of packages containing internal cavities. Number in parentheses below notes indicates sequence.
- L Required for leaded devices only.
- M Required for MOS & IGBT devices only.
- N Nondestructive test, devices can be used to populate other tests or they can be used for production.
- P Consideration should be made for whether this test is to be applied to a Smart Power device or substituted for a Q100 test. Elements for consideration include the amount of logic or sensing on the die, the intended user application, switching speed, power dissipation and pin count.
- S Required for surface mount devices only.
- T When testing diodes under Intermittent Op Life conditions the 100 degree junction temperature delta may not be achievable. Should this condition exist, a Power Temperature Cycling (Item 10alt) test shall be used in place of Intermittent Op Life (Item 10) to ensure the proper junction temperature changes occur. All other devices should use IOL.
- U For these tests only, it is acceptable to use unformed leaded packages (e.g., IPAK) to qualify new die going in the equivalent package (e.g., DPAK) provided the die size is within the range of sizes qualified for the equivalent package.
- V For bi-directional Transient Voltage Suppressor (TVS) devices, one-half the test duration in each direction shall be performed.
- W Not required for TVS devices. PV data in 4.2 will be after 100% Peak Pulse Power (Pppm) has been performed to rated Ippm current.

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)

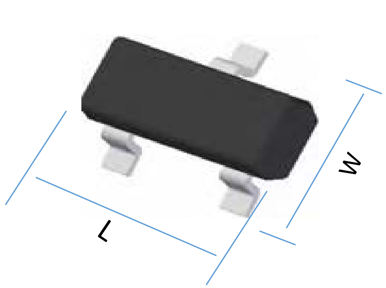
- Manufacturer should follow the Automotive Industry Action Group (AIAG) Production Part Approval Process (PPAP).

- 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

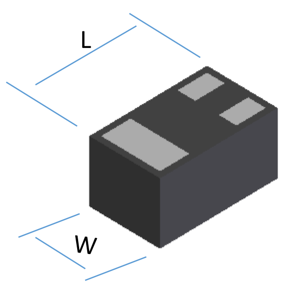
Package Examples for 2N2222 Bipolar Transistor

Automotive Grade



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

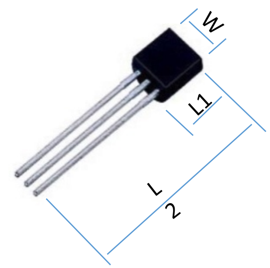
SOT-23



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

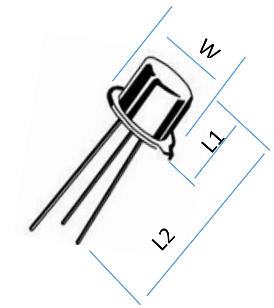
Commercial Grade



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

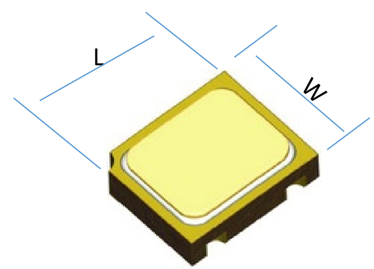
Plastic TO-92

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

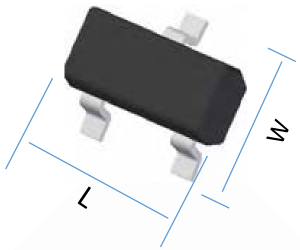


W = 5.84 mm/0.230 inch
H = 5.33 mm/0.210 inch
L = mm/ inch

Hermetic CerSOT – UB

Package Examples for Switching Diode

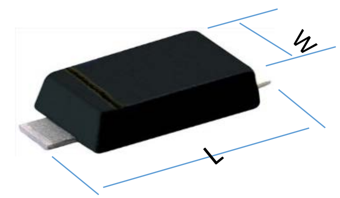
Automotive Grade



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

SOT-23

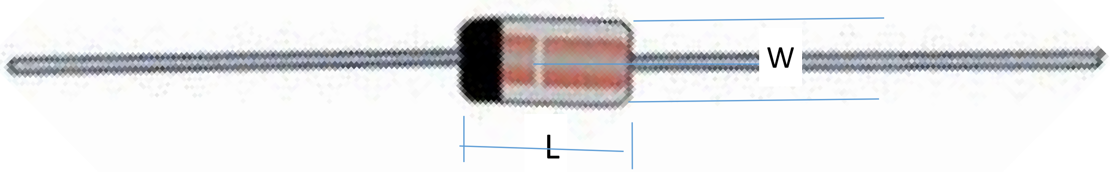
Commercial Grade



W = 0.152 mm/0.098 inch
H = 1.1 mm/0.043 inch
L = 3.0 mm/0.1181 inch

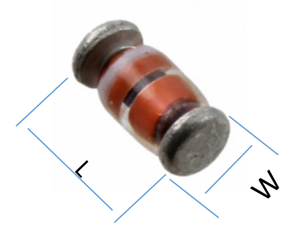
SOD-123

Military/Space Grade



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

DO-35

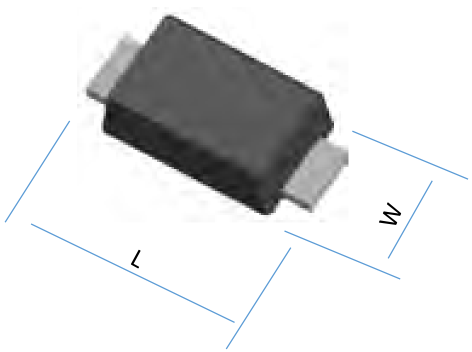


W = 1.70 mm/0.067 inch
L = 3.71 mm/0.146 inch

UR – surface mount

Package Examples for Schottky Barrier Diode

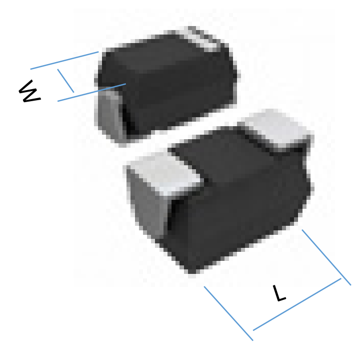
Automotive Grade



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

Powerdi123

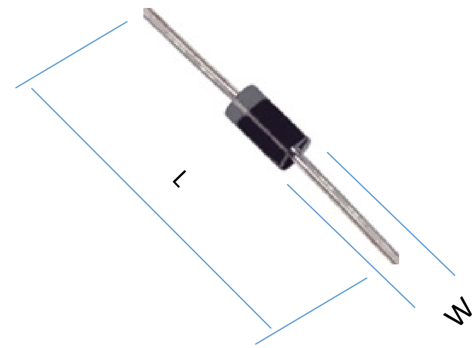
Commercial Grade



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

Quality System

- Automotive Quality System utilizes ISO 16949
- Process approach to Quality System
- Required audits:
  - Internal audits utilizing trained auditors be performed on a periodic basis.
  - External audit certification by 3rd party organization as per paragraph 7.4.1.2
  - External audits performed on a 2-3 year cycle

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

Audits

- ISO 16949 and ISO 9000:2008 audits
  - Process based audits
  - Internal audits
  - External audits
- Manufacturers (Ford, Delphi, Toyota etc) typically perform supplier audits for the following:
  - Process based audits
  - Initial qualification
  - Candidate suppliers
  - Component failures

Automotive Grade Discrete Components Evaluation at Navy Crane

- NASA/MSFC work with Navy Crane to evaluate the following device types from high volume auto electronics parts suppliers
  - Discrete bipolar NPN transistor
  - Fast switching diode
  - Schottky diode
  - Transient Voltage Suppressor
- Status
  - Parts ordered and received
  - Test travelers and test boards have been developed for the bipolar transistor and switching diode

Brainstorm List for Value of Parts Testing

- May not be statistically significant
- Automotive grade EEE parts do not easily cross over into equivalent commercial or military grade parts
- Automotive grade EEE parts have more limited operating parameters
- Most parts have pure tin leads leading to tin whisker concerns
- Will show if parts at random meet specs
- Have encouraged interactions with sources
- Provided focus for cost comparison
- Identified some test challenges

Customer Support

- Automotive grade EEE parts suppliers provide the following support to customers:
  - Application Support by Field Application Engineers
  - Return Material Authorization/Failure Analysis capability
    - Preliminary FA Report – 7 days
    - Final FA Report - 14 days or less
  - Warranty
    - Waiting on input for this – best guess is a year replacement