Use of COTS Parts for Long Term High Reliability Applications

James Loman, Ph.D.

Senior Distinguished Engineer

Prepared by:

SSL, a Maxar Company
3825 Fabian Way
Palo Alto, CA 94303-4604
USA

Prepared for:

European Conference on Space Components

ESA, Noordwijk, Netherlands, 11-13 March 2019

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Overview

1. We determined it is technically feasible and practical to use some limited commercial parts on large GEO spacecraft with 15 year life

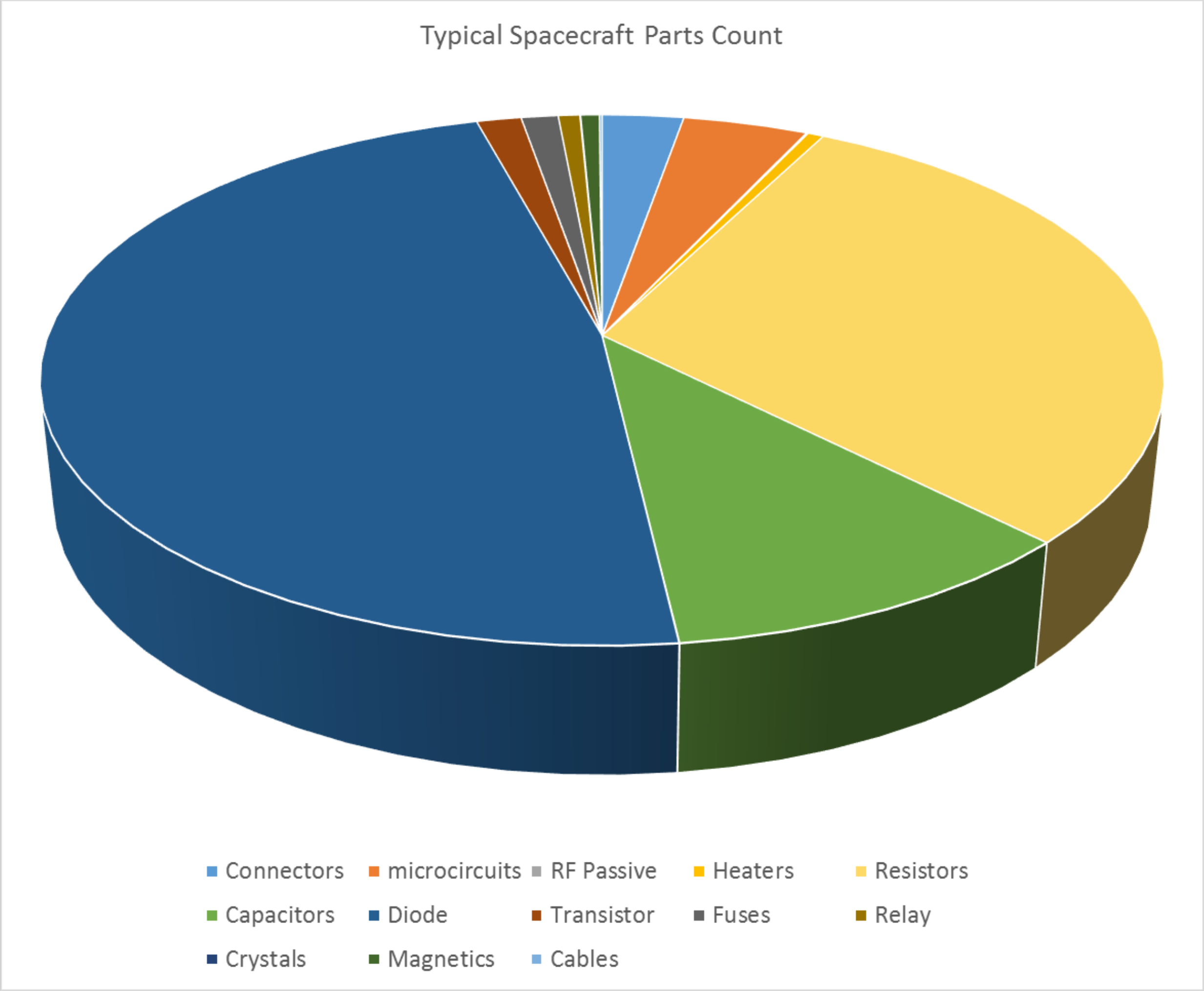
2. We now have our highest volume EEE part- a diode- as COTS

3. We now a complex COTS microcircuit performing battery management functions

4. We found a high barrier to entry which limits opportunities for existing designs

5. New design, small satellites at LEO represent better opportunities for use of COTS

EEE Parts Overview- Large SSL Geo Spacecraft



200K EEE Parts per Large GEO Spacecraft

Diode Project: Objective

- Project Objective: Use a commercial alternative for the most used Hi-rel diodes without impacting performance and reliability
  - Must be equivalent form, fit, function, reliability, performance
  - Must be drop-in replacement (no tray level redesign)

- Part types usage
  - Use 16,000 pieces of the most common diode per S/C- replaced half of these
  - Second most common type- 8000 per spacecraft
  - Many other opportunities to replace diodes elsewhere, but the return on investment is less and may not be worthwhile as a design change
  - COTS parts orders of magnitude less expensive

The simplest parts with the most savings and the least impact

Diode Project: Selection Criteria

- Selection criteria utilized
  - High Volume Commercial Process Control benefits
  - Same or similar electrical characteristics as current flight diodes
  - Drop-in replacement package only (no re-design)
  - Automotive grade preferred = qualification and compliance to AEC Q101 standard

Hi-rel Type	COTS TYPE	Mfg.	Grade	V rated	I rated	Package Fit
Most Used Diode	1	A	Automotive	75 V	250 mA	Fits ok for all applications
	2	B	Commercial	75 V	250 mA	OK for some applications
2nd Most Used	3	B	Automotive	200 V	2 A	Fits ok for all applications
	4	C	Commercial	150 V	2 A	Fits ok for all applications

Diode Project: DC Electrical Testing Results Summary

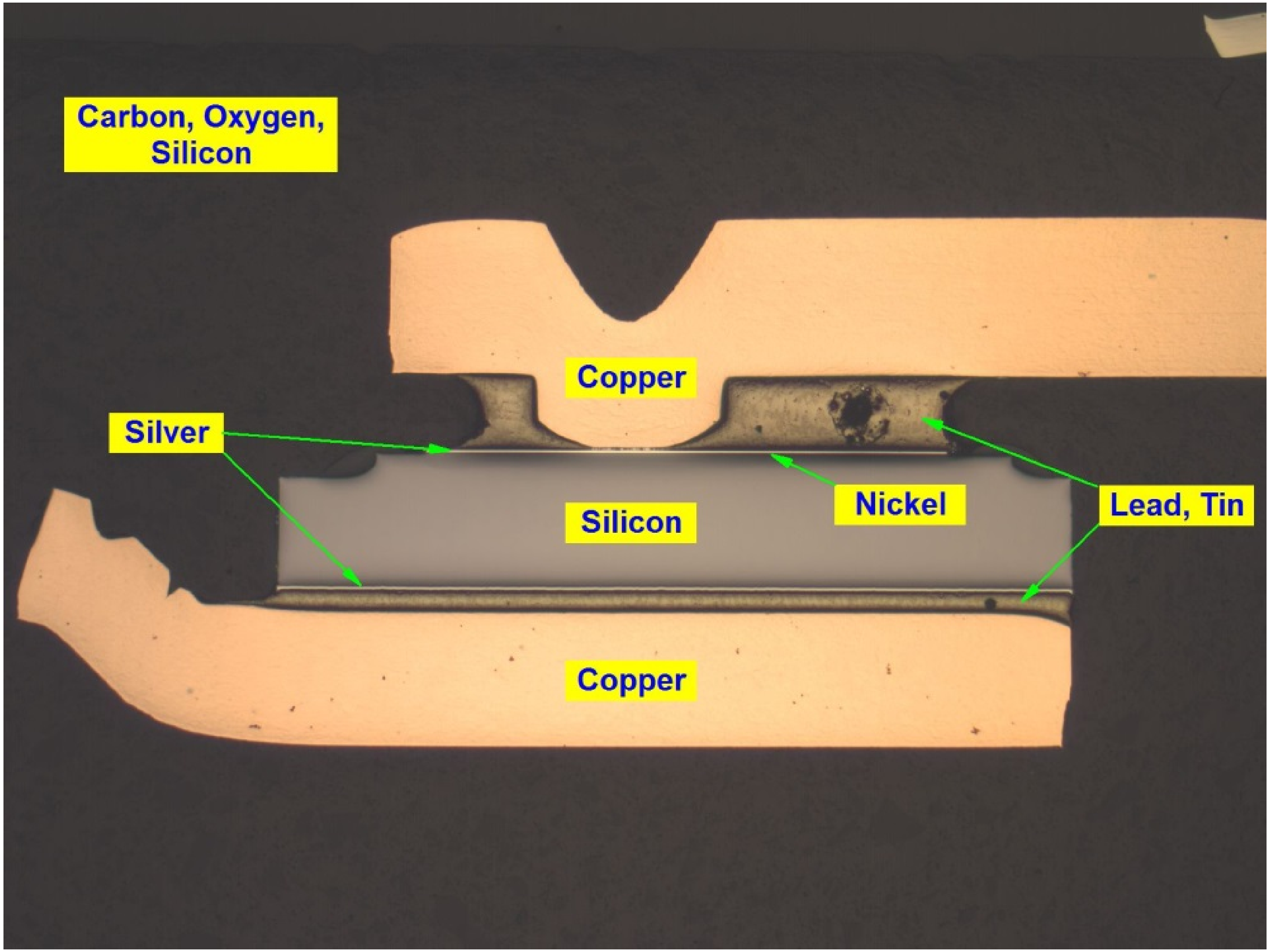
- All diodes performed within their respective Data Sheet limits.
- Compared to Hi-rel parts, the commercial diodes had tighter distributions and equal or better values for most parameters
  - Breakdown voltage: higher and standard deviation ~1/3 of Hi-rel parts
  - Forward voltage: similar to Hi-rel
  - Leakage current: much lower (>10x less), tighter distribution
  - A few obvious outliers existed, however all parts well within spec
  - Forward voltage & leakage notably better at Hot Temp (+125°C)
- Dynamic parameters were not tested
  - Limited replacement in a few instances

COTS diodes data shows equivalent or better performance than the Hi-rel parts

Diode Project: Other Evaluations

- No issues found in any of the following
  - Outgassing well below required TML of 1.0%, CVCM of 0.1%
  - All passed radiation at 300 Krad(Si)
  - Manufacturability Assessment Plan- existing processes were unchanged
  - Applications Assessment Plan- existing designs were unchanged
  - HALT testing- existing designs were unchanged

- Vendor Audits are not possible
  - Rely on our screening on a per roll basis to ensure no changes


Carbon, Oxygen, Silicon
Copper
Silver
Nickel
Lead, Tin
Silicon
Copper

Diode Project: Environmental/Qual Test Plan

- Three best fit qualification documents were compared for plastic/commercial parts: NASA, ESA and Automotive Council (in that order)
  - NASA PEM-INST-001, ECSS-Q-ST-60-13b, & AEC-Q101
  - AEC tests all utilize a 77pcs sample size (3x consecutive lots)
  - Larger sample size needed to demonstrate equivalent reliability to space grade parts
  - Obviously “Not Applicable” tests excluded: Cavity parts only tests: hermeticity, wire bonded part tests, die shear, vibration/shock/constant acceleration

- Constructional analysis showed pure tin on leads, and Cu wirebonds or lead frames as typical COTS techniques (unusual for Hi-rel parts)
  - No Sn whiskers found despite stringent test
  - Tin/Lead eutectic solder use in-house mitigates any whisker problem
  - “Pure tin” finish is a very thin matte (not likely to grow whiskers)
  - Cu is often listed as a “concern” for high reliability but we could discern no issue

Diode Project: Reliability Life Test Plan & Failure Rate

- Purpose:
  - Demonstrate that commercial diode has a failure rate comparable to the currently used space grade (Hi-rel) diode
- Approach:
  - Accelerated life testing was used to reduce test time using temperature and voltage as acceleration factors
  - This approach is well-established and accepted in both the space and commercial industries
  - To demonstrate failure rate (FR) of 1 FIT (failure in time, 1 FIT = 1 failure/10^9 hours) without accelerated testing – 1,000 devices would need to operate for 10^6 hours or 114 years
- Accelerated Testing Conditions:
  - Targeted FR = 0.85 FIT @ 67°C operating junction temperature
  - Test conditions are T_A = 150°C, V_R = 80% rated (HTRB test)
  - **538/0** pcs must be tested for 1,000 hrs OR **269/0** pcs for 2,000 hrs

Diode Project: Test Plan Results- Highest Use Case

- Commercial Diode (Type 2)
  - Passed all tests, and better electrical performance than Hi-rel diode
  - Does not fit physically in all applications due to slightly smaller size
  - To accommodate other applications, would require board re-layout

- Automotive diode (Type 1)- Two issues
  - Several failed during the life test. Unknown if it was intrinsic to the diode or a testing issue
  - A second issue was found during Intermittent Operating Life (IOL) testing
    - Solder joints did not hold up under thermal stress
    - The root cause was insufficient strain relief due to their pins configuration.
    - No practical solution to this problem seemed worth pursuing

Commercial diode in this case proved more reliable than automotive, but limited application due to size

Microcircuit Project: Quality and Reliability

- Use of high volume automotive grade microcircuit for battery management was a vision for substantial costs savings and implementation simplicity
  - Unlike diodes, the complexity of the microcircuit is very high
  - A single low cost chip replaces a rad hard board of electronics
- Parts were obtained from a single date code from a distributor
- Complete upgrade screening was performed following NASA PEMS INST-001
- Microcircuit yield through screening was 100%, demonstrating the vendor produces very high quality and reliability microcircuits
- Complete group screening was performed, only anomalies noted were some C-SAM rejects post life test
  - DPA cross sections of chips showed no voids or delamination
  - Defects noted were ascribed to CSAM test artifacts, not real defects
- Cost of screening and group testing was ~100X the cost of the parts

Automotive Grade Microcircuit: high quality and reliability
Upgrade screening added cost but not value

Microcircuit Project: Radiation Effects

- Tested total dose and low and high dose rates
  - Fully specification compliant at 10 Krad(Si) & useable at 15 Krad(Si)
  - Typical rad hard parts are 100 Krad(Si)
  - Nonetheless useable with spot shielding and placement location
- Tested Single Event Effects (SEE) at LBNL
  - Single Event Upset (SEU): Anomalous readings were occasionally observed in a cell voltage or thermistor measurement, non-persistent between readings (interval of 1 sec.)
  - Single Event Functional Interrupt (SEFI): Persistent disruption in the General Purpose Input/Output pins (GPIOs) used to measure thermistors. Implemented software to detect and reset SEFI
  - Single Event Latchup (SEL): Single event latchup (high current) observed on the low voltage input at a very low rate (<1 / 100 years). Samples which were appropriately protected and had a robust detection and reset schemes implemented showed no signs of performance degradation or damage subsequent to testing.
- Rad testing NRE ~ similar in cost to upgrade screening

Automotive Grade Microcircuit: not designed for space
Can be made to work with circuit modifications
SEE testing and solutions: complex / costly

- Savings on a per-part basis will not overcome non-recurring costs involved unless the volumes are significant (thousands used)
  - Manufacturing assessment- determine fit, function, pure tin (Sn) assessment
  - Design assessment
    - will it work the same over temperature
    - revisit Worst Case Analysis
  - Switching tests are needed for certain applications
  - Test in breadboard or EM- need to show that it works
  - Change drawings, bills of material and part numbers
  - Unit level testing , probably re-qualification
  - Brief customers & request contractual relief

High barrier to entry for changing a part in exiting designs

Lessons Learned

Lessons learned during this project

1. "Drop in" replacements for space grade parts are difficult to find. Extensive use of COTS requires redesign and requalification. It's easier to use COTS in a new design rather than retrofit an old design

2. Some vendors of COTS parts produce suitable high quality & reliability parts

3. Due to low cost construction techniques, some COTS parts may not be suitable for long term use

4. Automotive parts may be high quality and reliability, but use in space can require extensive radiation testing, shielding and Single Event Effects mitigation

Opportunities exist to provide more affordable systems, but it's very important to do a full qualification to ensure reliability