Mission Success Starts With Safety

Implementation of COTs hardware In Non Critical Space Applications

A BRIEF TUTORIAL

Presentation to 17th Annual Microelectronics Workshop JAXA, Tsukuba, Japan, October 20, 2004

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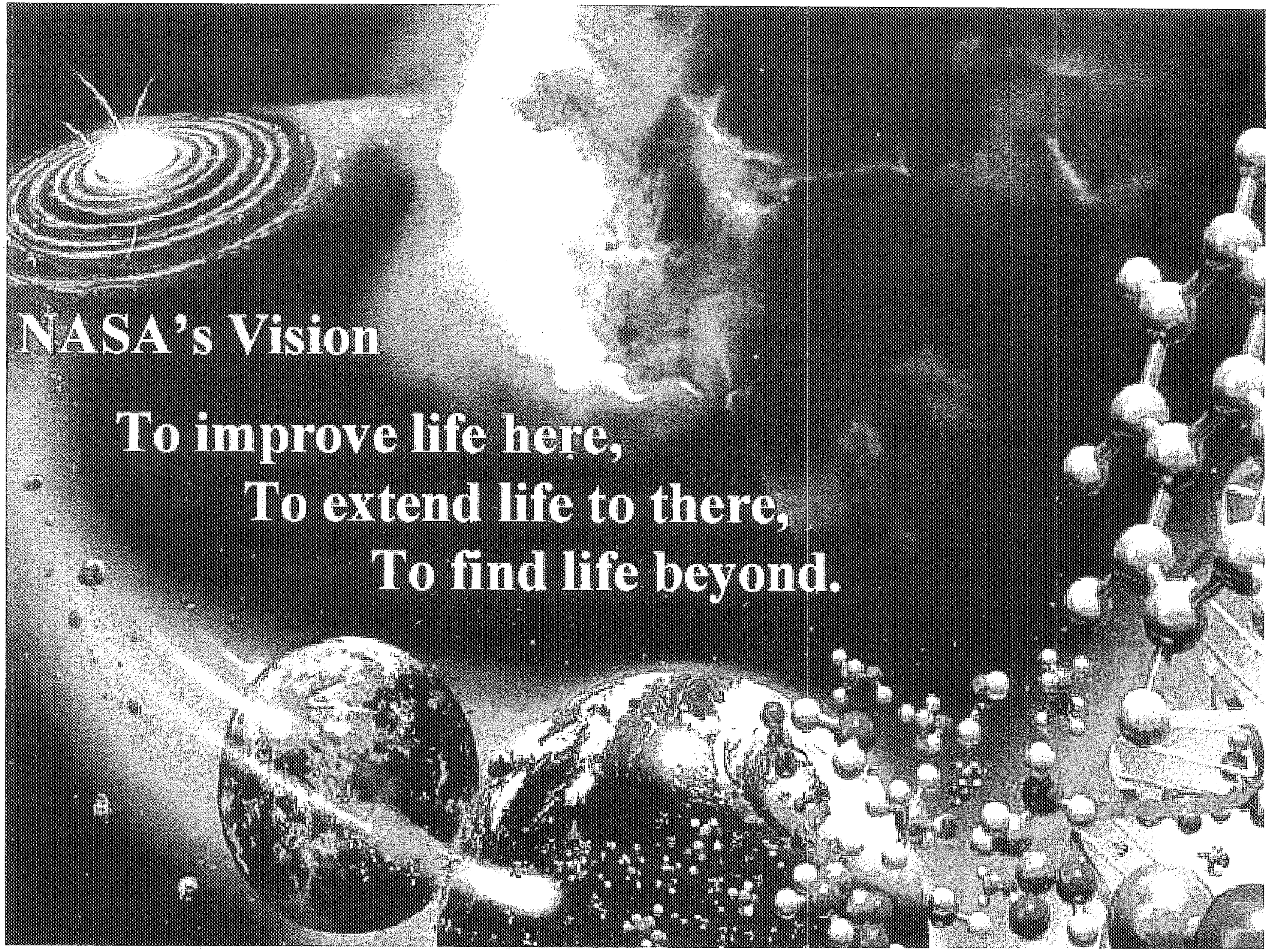
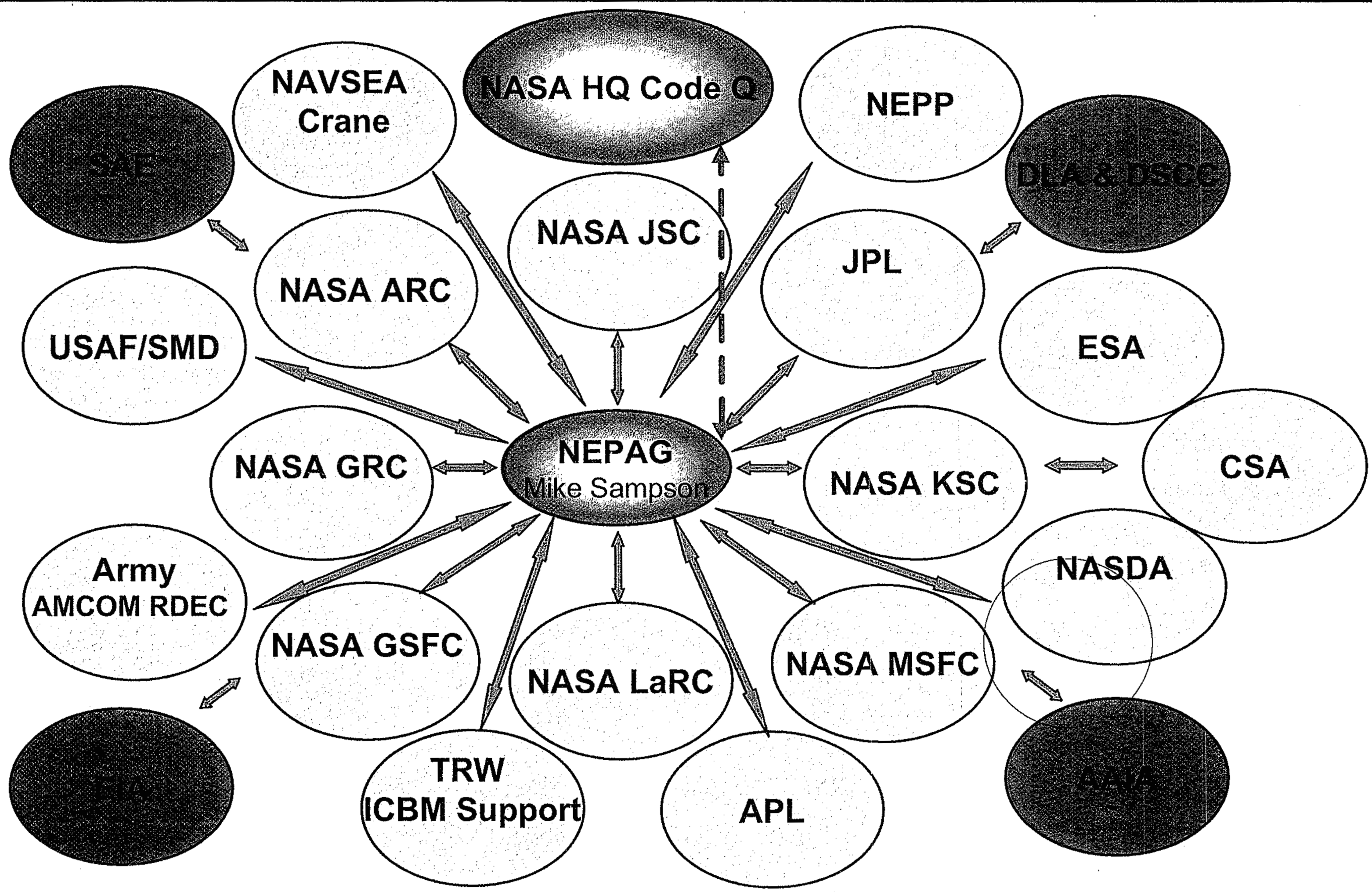
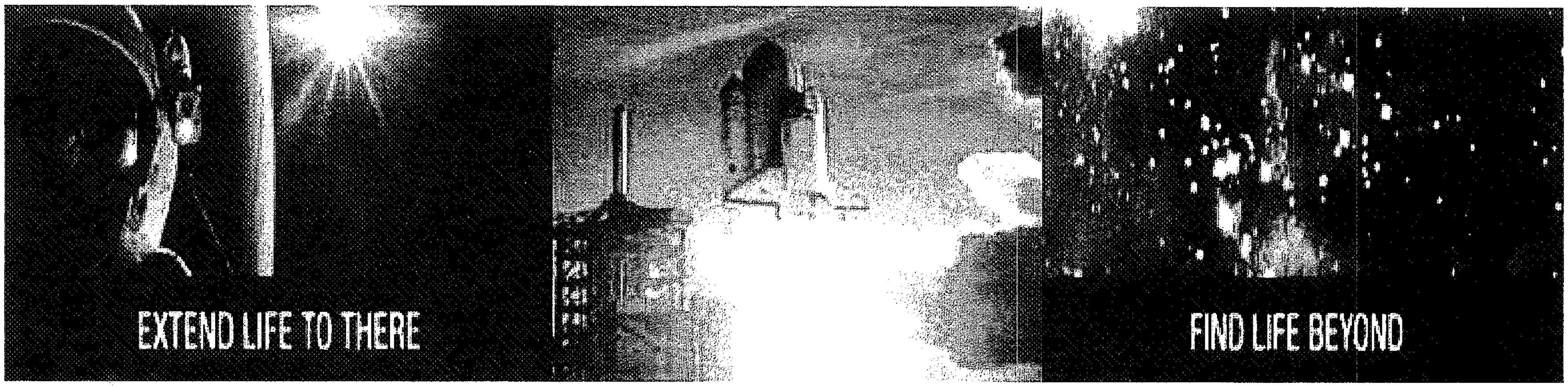

NASA's Vision
To improve life here,
To extend life to there,
To find life beyond.

NEPAG "Extended Family"



Associates ☐ Partners ☐ NASA Centers

Overview



ELECTRICAL, ELECTRONIC AND ELECTROMECHANICAL (EEE) PARTS ENGINEERING

- EEE Parts Selection Process for non critical COTs hardware
    - (Evaluation of high criticality hardware is not covered in this presentations)
  - Today's Major Challenge for EEE Parts Assurance - Commercial-Off-The-Shelf (COTS) component and box level hardware
- Workmanship requirements overview for COTs

Traditional EEE parts Categories

Level 1 Microcircuits

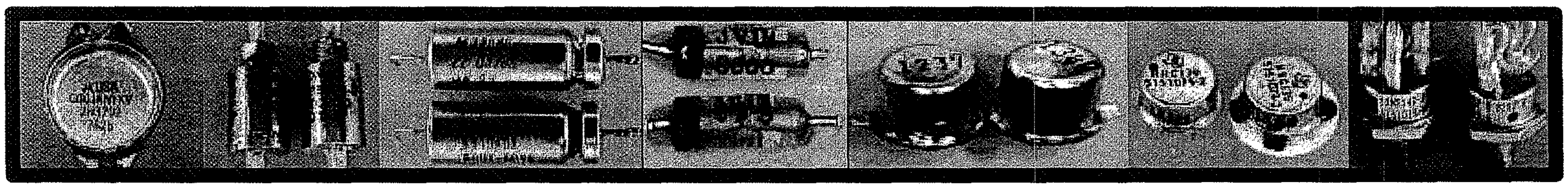
Level 1 microcircuits are defined as those currently qualified to

- MIL-PRF-38535 "Integrated Circuits (Microcircuits) Manufacturing, General Specification for" as QML Class V or,
- MIL-M-38510 "Microcircuits, General Specification for" as QPL JAN Class S or,
- Space quality source control drawings (SCDs), where QML/QPL does not exist, which meet all of the technical requirements of MIL-STD-883, Method 5004 and 5005 for a Class S device
- National Space Development Agency of Japan (NASDA) QTS Class I

Level 2 Microcircuits

Level 2 microcircuits are defined as those currently qualified to

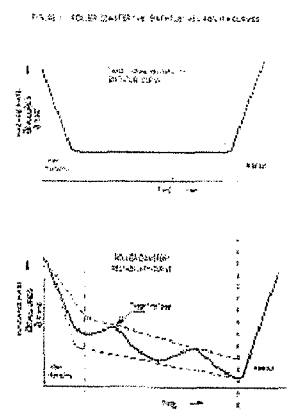
- MIL-PRF-38535 "Integrated Circuits (Microcircuits) Manufacturing, General Specification for" as QML Class Q or,
- MIL-M-38510 "Microcircuits, General Specification for" as QPL JAN Class B, when modified/screened per mission requirements for space
- National Space Development Agency of Japan (NASDA) QTS Class II



EEE Parts Background

EEE Parts Background [1]

- Parts have traditionally been viewed as the source of failure in spacecraft systems.
- This was true for earlier parts because of quality and reliability problems with evolving microelectronics.
  - Recent data shows that parts and quality factors are the minor constituent of spacecraft failures.
- In the 60's, MIL-STD-883 Quality and Reliability Assurance procedures were developed for Monolithic Microcircuits.
- In the 70's, additional mil specs were drafted to define requirements for "space-rated," or Class-S components.
  - Screening effectively weeded out substandard components and screening became a standard building block for spacecraft systems.
- 80's & 90's - Electronics manufacturers heavily automated their processes to increase quality and reliability while decreasing cost for markets such as automotive, consumer electronics, and machine-tools.
- [1] Sarsfield, Liam, "The COSMOS on a Shoestring,", Santa Monica, CA, RAND MR-064-OSTP, 1998, pp. 119, 139

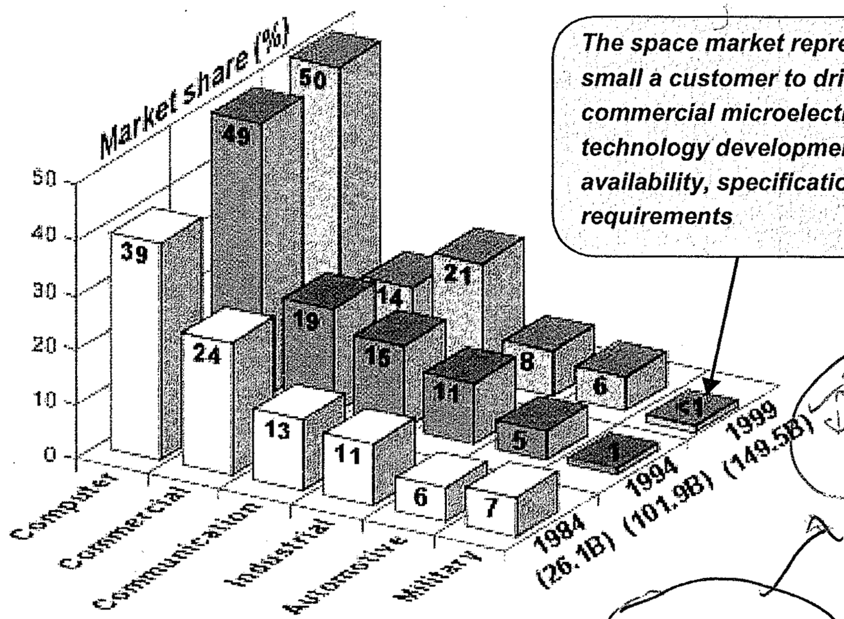


❖ *Requires the EEE Parts Engineer to understand the part application rather than just selecting parts from an approved parts list.*

EEE Parts Background
The Challenge

Relative Size of Space Market for Microelectronics

Military and Space grade parts do NOT dominate the component industry



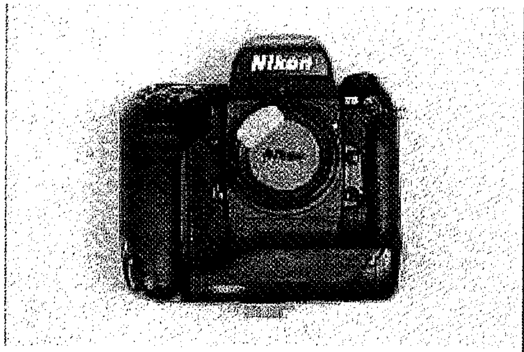
The space market represents too small a customer to drive commercial microelectronics technology development, availability, specifications and requirements

in public domain? If not pull out

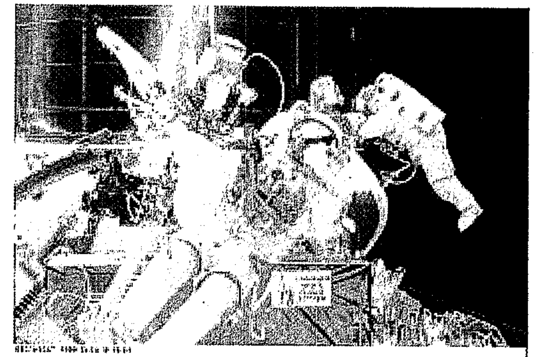
Source: WSTS and SIA

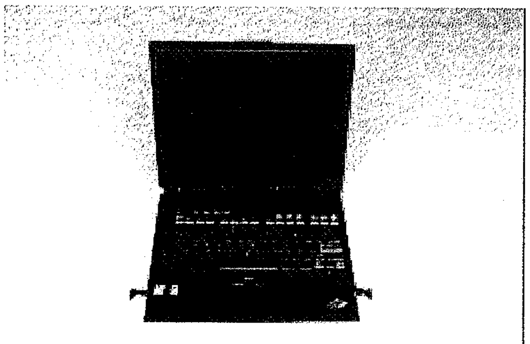
The goal and the challenge for the space community is to take advantage of the availability and performance of commercial microelectronics for space systems, while retaining sufficient radiation tolerance and reliability to insure mission success

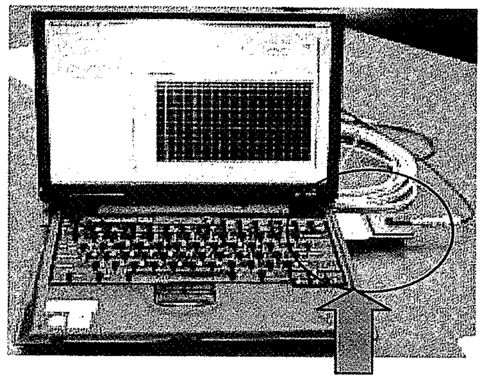
COTs Hardware Plays a Vital Role in Space Programs

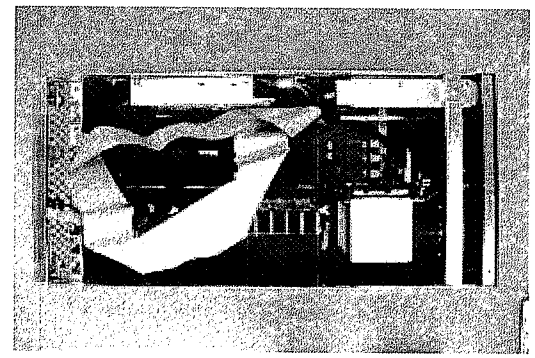


Photos taken in space with COTs cameras









Laptop Computers used on the International Space Station

Cable Time Domain Reflectometer tester for ISS

Video Imaging processor

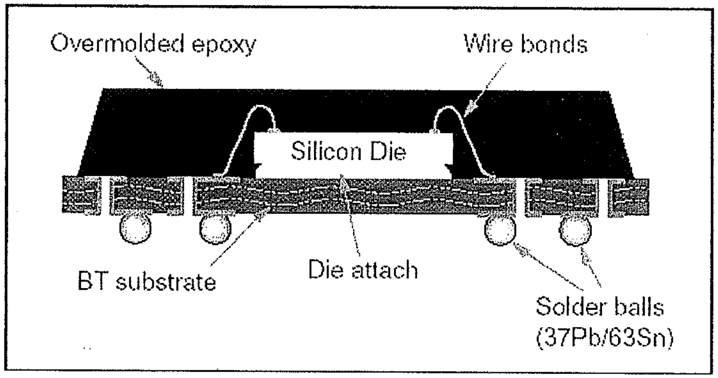
Requires significant modifications for use in Space

All hardware must be evaluated for the application

COTs items were modified for Space applications

Radiation testing, conformal coating, workmanship evaluation, flammability, burn-in etc.

COTs Hardware Challenges
Hardware Construction



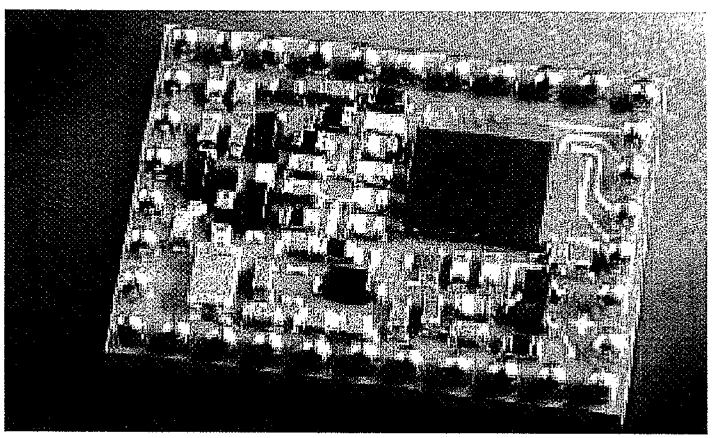
More than ever, NASA must select advanced technology parts for use in the space environment.

Methods other than traditional "look on the approved parts list" must be used to meet the challenges of using new technologies in space.

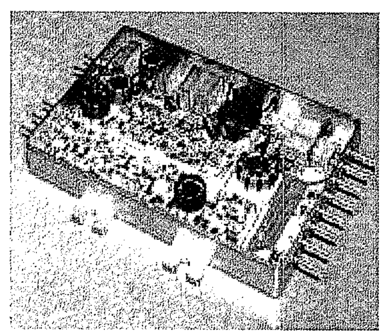
Previously qualified Military and Space level parts are not always available for new applications.

Selection of Best-In-Class components and vendors is a vital part of ensuring mission success.

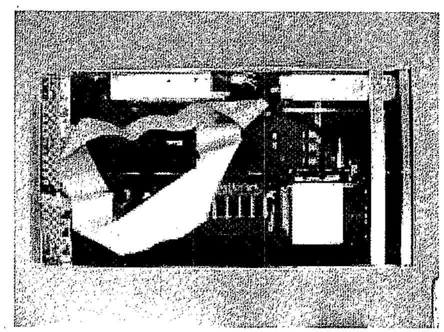
Requires a high skill level of parts and process expertise to ensure mission success.



Communications modules



Hybrids



Processor system requires modifications for space applications

COTs Hardware Challenges
Safety Factors

Space environment, confined volume, human factors, and vacuum conditions require proper material selection

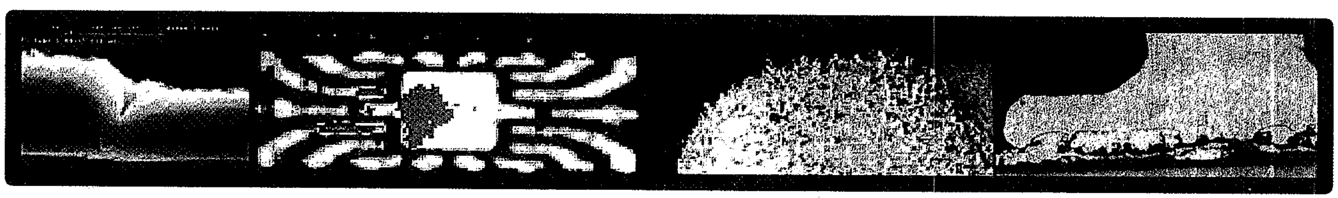
- Out gassing/Off gassing (NASA certified materials referenced in MAPTIS)
  - Can contaminate critical components such as camera lenses
- Flammability
  - Spacecraft and human safety
- Toxicity
  - Critical because humans are in confined areas
- Hermeticity
  - Components exposed to vacuum can implode/explode without proper venting
  - Components operate differently in vacuum – internal elements of non hermetic components can be affected
  - Oil canning of the package
- Thermal
  - Traditional heating and cooling methods such as convection are not the same in 0-G as in gravity
  - Air flow for cooling must now be forced airflow
- Mechanical
  - 0-G imposes different mechanical challenges
    - Items such as traditional loose CD player trays will not function. The CD will float.
- Ionizing Radiation
  - Can latch-up a component or cause upsets disabling hardware

EEE Parts Selection Process for COTS hardware

EEE Parts Selection Philosophy

- Assure all EEE parts used in spacecraft hardware designs are of a quality and reliability level commensurate with the mission environment and requirements.
  - May require redundancy
  - Could require additional screening
- Allow the use of most advanced parts technologies that are generally available in the commercial market place, with emphasis on using those that have a proven reliability track record and meet the specific expected application environment.
  - Laptop Computers
  - 200 MIP processors
- Focus on Best In Class (BIC) manufacturers

❖ *Caution: Not all vendors and manufacturers produce the same quality level hardware*



EEE Parts Selection Process

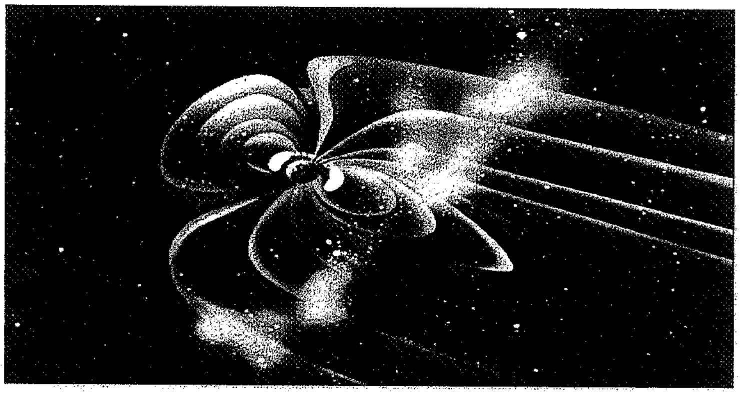
Five key steps to selecting Best-In-Class EEE Parts Manufacturers

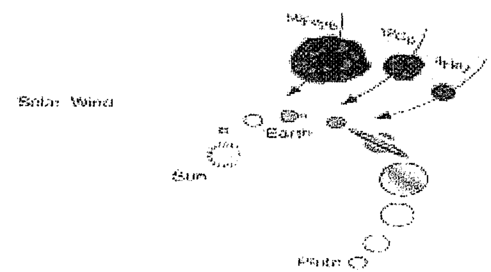
1. Definition of the application environment
   - **Determine the EEE Part application environment**
   - **Understand design feature requirements**
2. Part identification and selection
   - **Close interaction between Design and Parts Engineering**
   - **Determine the best technology type available for the application**
3. Identification and Qualification of manufacturers
   - **General assessment and specific family/line assessment**
   - **Vendors overall commitment to quality and reliability**
4. Validation of line and part capability to meet environmental requirements
   - **Qualification results, NASA's GIDEP ALERTs**
5. Establish and maintain an ongoing relationship with with qualified manufacturers

❖ *Requires an understanding of the Manufacturers and their processes*

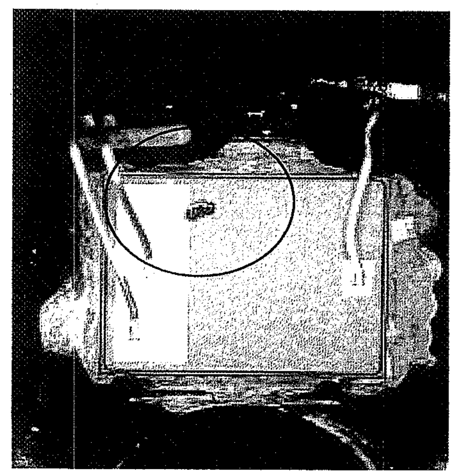
Ionizing Radiation Effects

Ionizing Radiation can disable hardware including COTs hardware



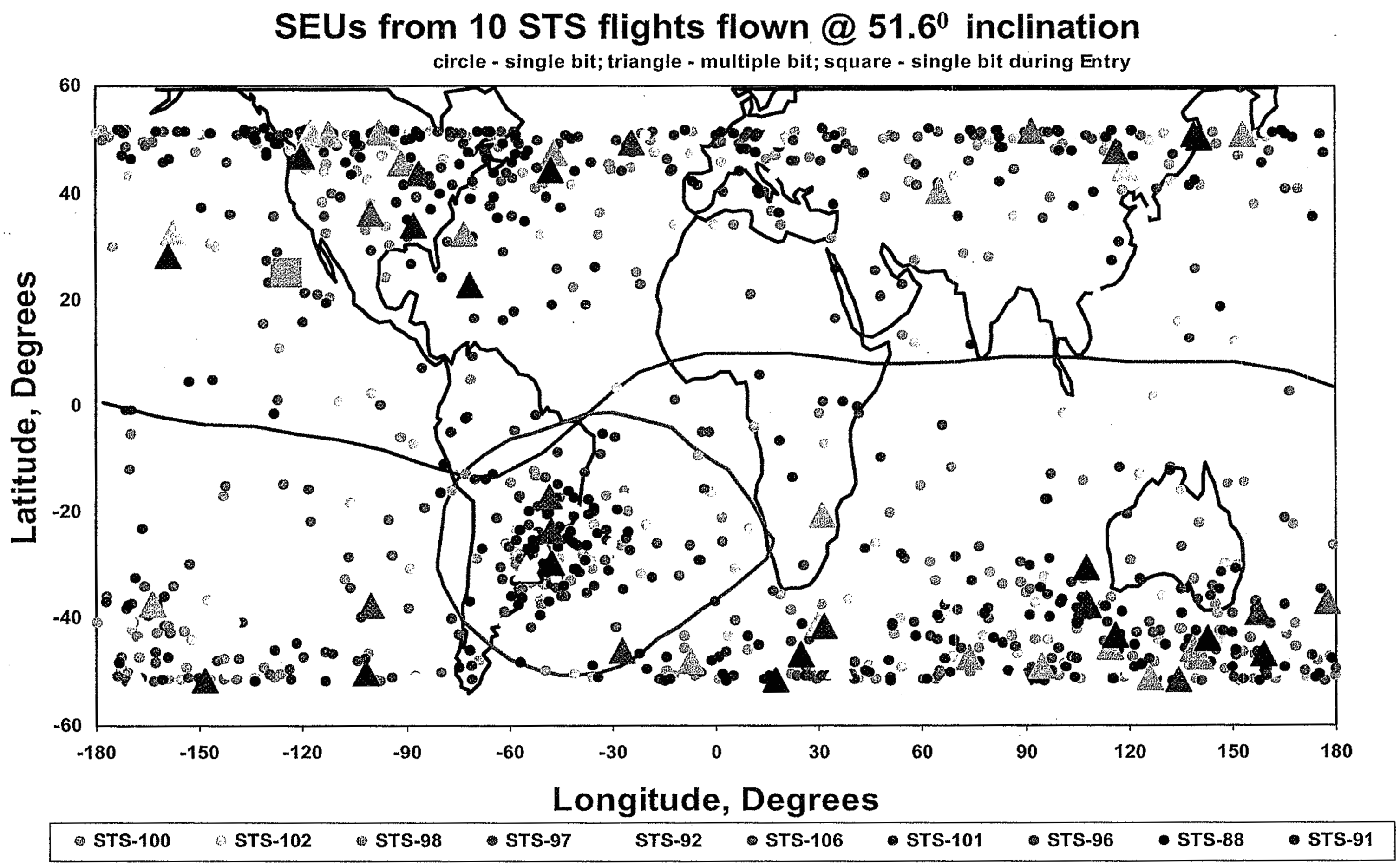


FET used in a laptop docking station experienced a destructive latchup during high energy proton testing



COTs Hardware is susceptible to SEU's

SEU's collected on numerous Shuttle flights



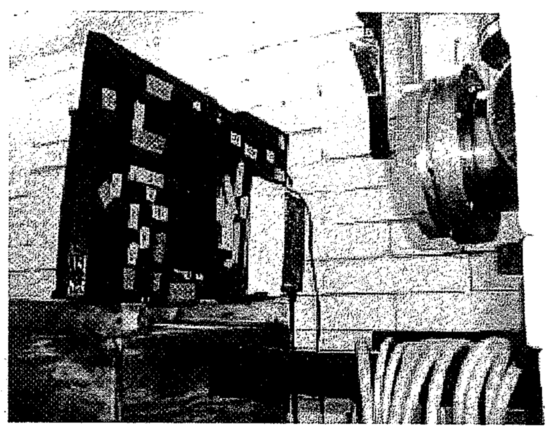
Ionizing Radiation

Test Early and Test Often

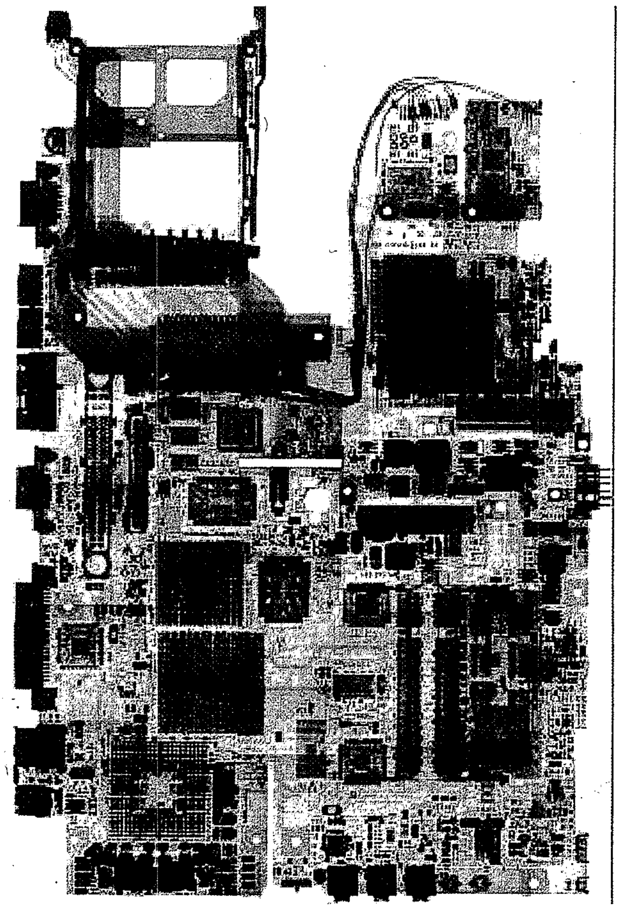
Example of High Energy Proton Testing

Test Preparation

- Visual parts inspection
  - manufacturer & part number
  - lot-date code
  - function
- X-ray board & assemblies
- Beam grouping based on function & priority



Laptop in the high energy proton beam



X-Ray to identify microcircuit die regions

Example of Results from High Energy Proton Testing

Primary Docking Station:

Error #1: Position #5 (unknown parts) Computer hang/crash (machine check exception); no recovery; power cycle required

Occurred at 337 rads (Si) (fluence of 5.63 E9) subsequent reboot OK

Error #2: Position #17 (part of A/C power supply)

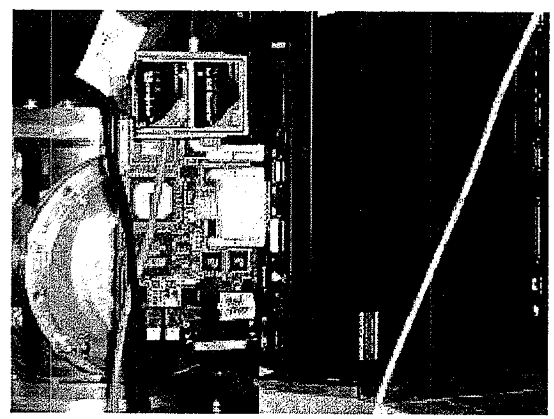
Test program errors, followed by computer crash; no recovery; power cycle required

Occurred at **34 rads (Si)** (fluence of 5.66 E8)

Docking station would not turn back on! -- **Destructive Latch** or permanent failure assumed!

Backup Docking Station:

Error #1: Position #14 (Silicon Image Si10648CL160) Computer crash; no recovery; power cycle required
Occurred at 236 rads (Si) (fluence of 3.94 E9)
Docking station would not turn back on!
Destructive Latch or permanent failure



Predicted MTBF of 402 days for destructive latch up

Test early and test often – Lot variations are real

Manufacturing Standards Vary for COTs Hardware

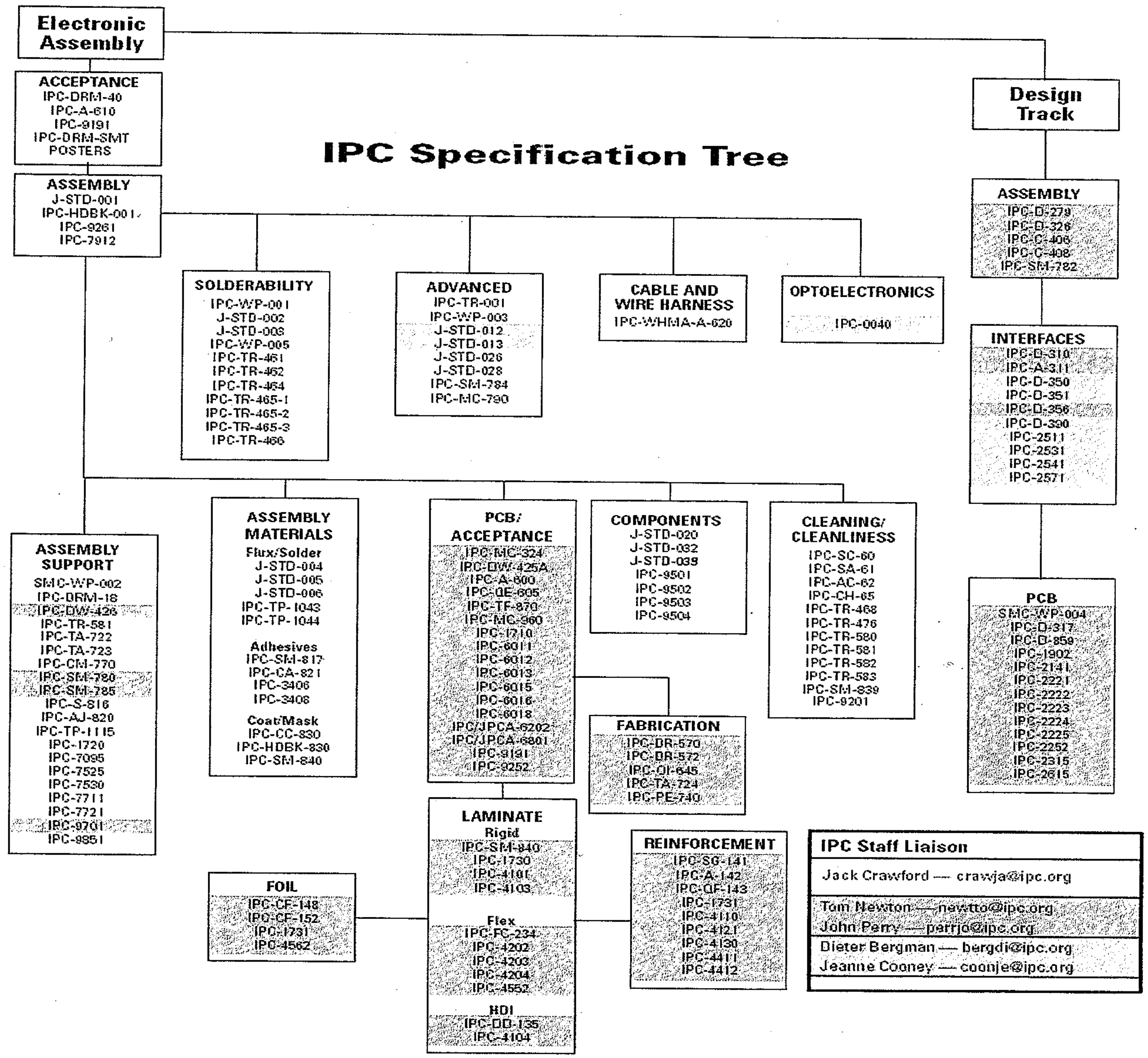
NASA Workmanship Standards List

- NASA-STD-8739.1 Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies
- NASA-STD-8739.2 NASA Workmanship Standard for Surface Mount Technology
- NASA-STD-8739.3 Soldered Electrical Connections
- NASA-STD-8739.4 Crimping, Interconnecting Cables, Harnesses, And Wiring
- NASA-STD-8739.5 Fiber Optic Terminations, Cable Assemblies, And Installation
- NASA-STD-8739.7 Electrostatic Discharge Control (Excluding Electrically Initiated Explosive Devices)
- NASA Technical Standards Program: http://standards.nasa.gov/
- NASA Workmanship Technical Committee: http://workmanship.nasa.gov/htm/index.html

- *NASA-STD-8739.7 ESD is now superceded by ANSI/ESD S20.20-1999*
- *Other Standards such as J-STD-001, IPC6012 are under review*

Typically not used in manufacturing of COTs hardware

Reliance on Industry IPC Standards for COTs



Workmanship Evaluation Process

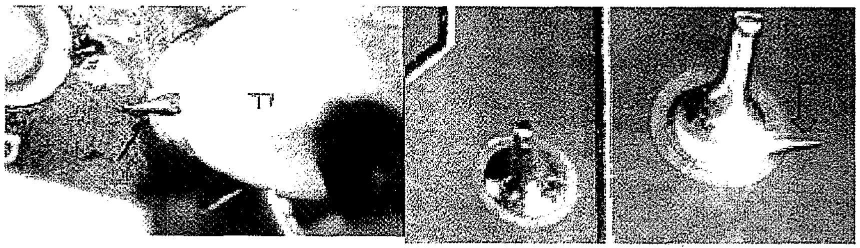
Workmanship standard certification to ISO, IPC, NASA-STDs etc. is no guarantee the vendor will produce high quality reliable hardware

- Key observation elements to focus on during a vendor survey
  - General appearance
    - Appearance is an indication of the attitude of a company
  - Casual conversations with employees
    - Listening to employees often reveals the pulse of the company
      - Excessive praise or constant complaints
  - Statistical Process Controls (SPC)
    - Evidence of continuous process improvement and is it being used for CPI or just show
  - Dedicated touch-up personnel
    - High employee number for dedicated touch-up often reveals a process problem
  - Mixture of flight and non flight hardware in the same area
    - Often reveals a lack of discipline to ensure hardware pedigree
  - Equipment maintenance and calibration
    - Is hardware close to end of calibration? Is the equipment clean or heavily used?
    - Maintenance records for excessive down time could show process problems
  - Design for manufacturability process includes layout for automation

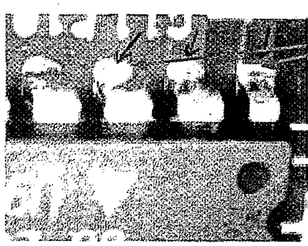
Workmanship

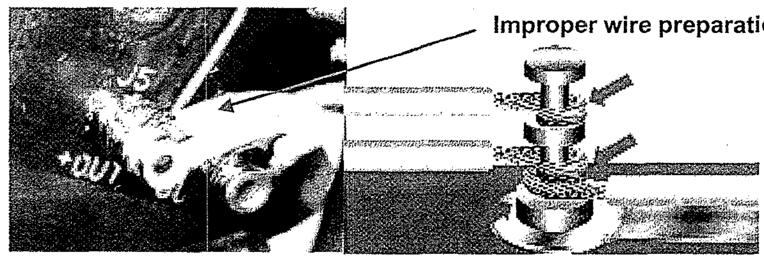
Workmanship of hardware affects overall hardware reliability - good or bad

Poor workmanship can introduce latent failures
Cracked component seals due to improper component heating
Corrosion from improper cleaning
Corona as a result of icicles
Fractured solderjoints causing intermittent failures
Broken wires as a result of improper wire fastening and stress relief



UNACCEPTABLE SOLDER SLIVERS
Solder slivers are an indication of improper process control.
NASA-STD-8739.3 [13.6.2.c.4]

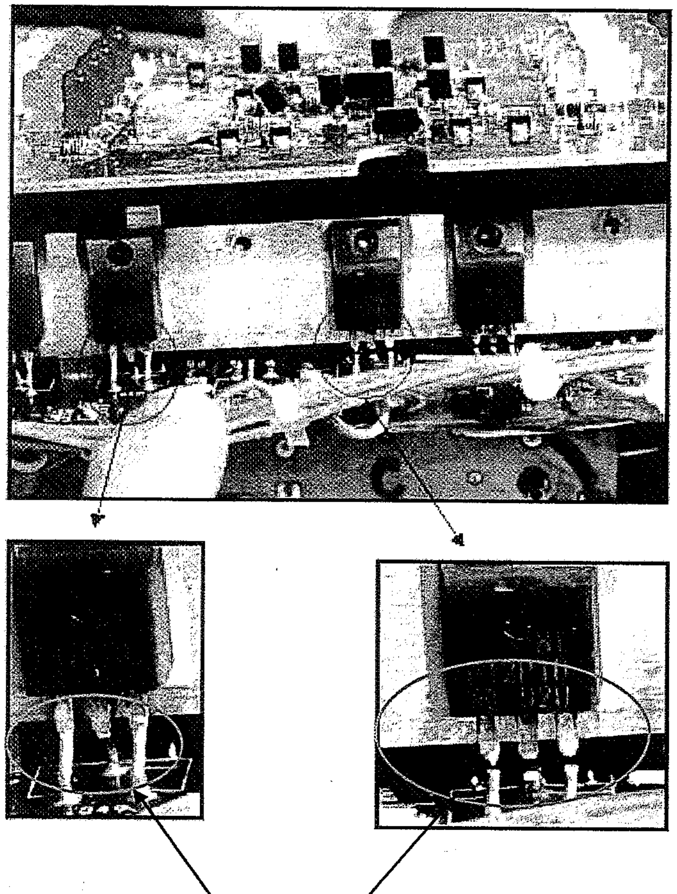




GENERAL REQUIREMENTS WRAP ORIENTATION
Conductors may be wrapped clockwise (CW) or counterclockwise (CCW) to the terminal, but the curvature of dress shall be such that the wrap will tighten against the terminal if the conductor is pulled.
NASA-STD-8739.3 [9.1.8]

Examples of Hardware Failures

Improper mounting and strain relief



Broken Leads

No evidence of component staking

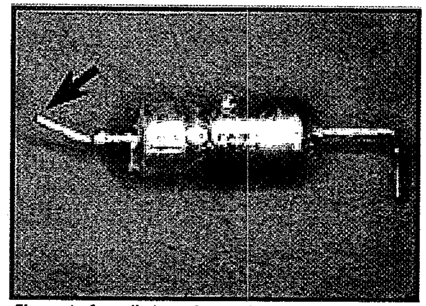


Figure 1. Overall view of capacitor. Arrow points to broken lead. Note length of lead to the bend on right. There was no evidence of residual staking material on the Mylar sleeve. 3.5x

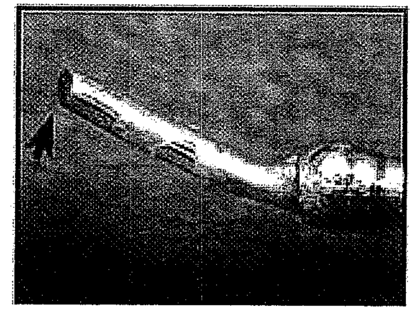


Figure 2. Close-up of wire lead showing joint at right. Arrow points to fractured lead. 12x

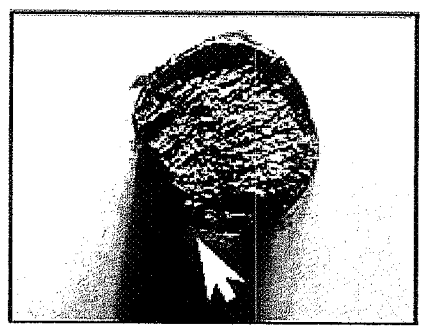


Figure 3. End view of broken lead. Low-angle light captures the typical 'beachmark' appearance of a fatigue failure. Note that the side of the lead between the white arrows has been flattened. The beachmarks radiate from this side, indicating that the fatigue crack originated on the flat side of the wire. 64x

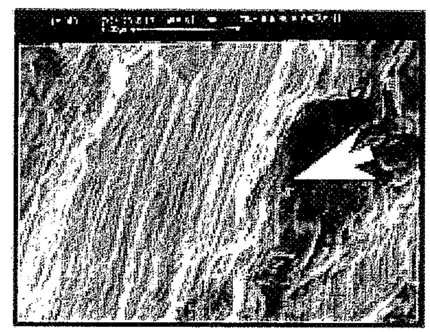
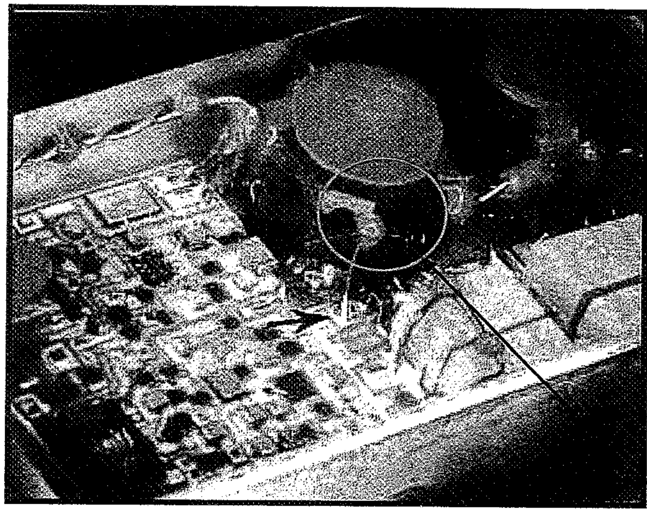
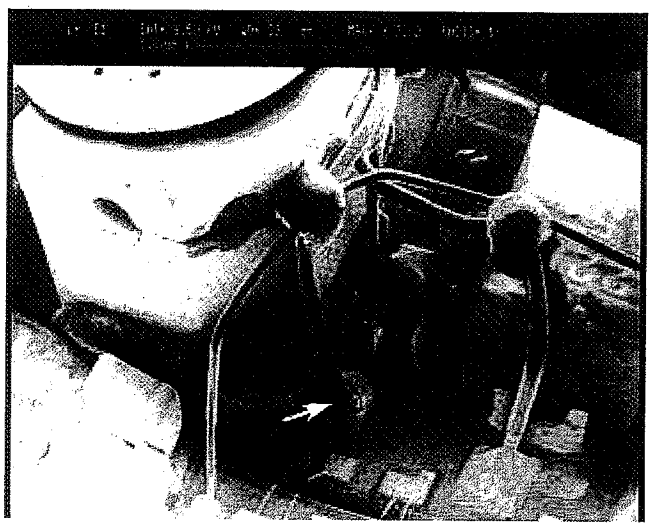


Figure 4. Viewed under a SEM, the surface of the fractures reveals thousands of parrallel striations indicating that the lead failed due to high-cycle fatigue. The crack progressed in the direction of the white arrow, roughly at right angles to the striations. Each flexure causes the formation of a striation. 600x

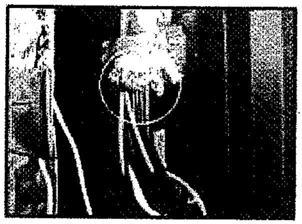
Examples of Hardware Failures





Improper staking nullified wire strain relief

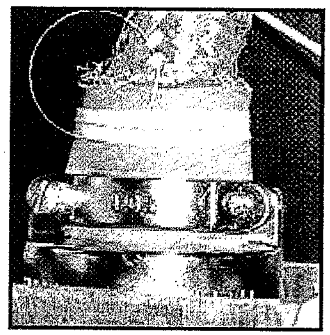
Examples of Hardware Failures

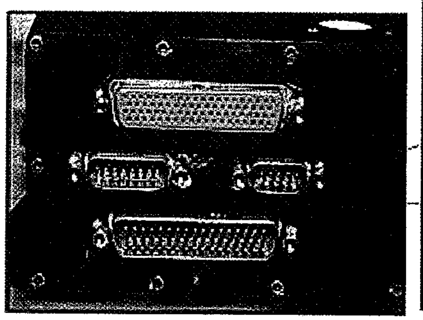


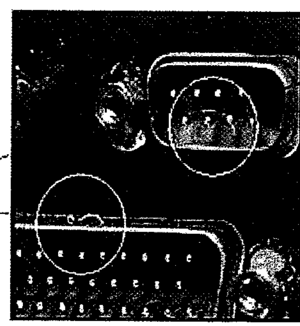
Exposed braided shield over wire barrier

Closer inspection shows improperly trimmed ends

Additional improperly trimmed ends on another connector assembly





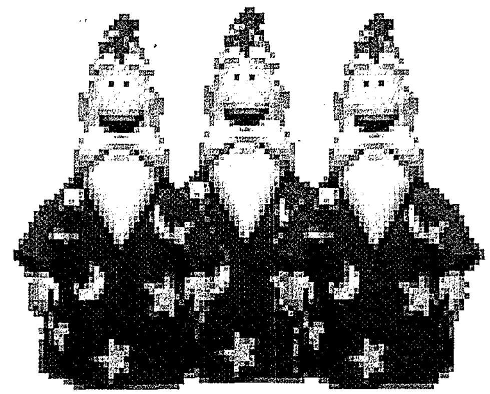


Seemingly small problems can still cause major failures

Braid strand lodged inside connector shorting signal pins

Summary

It does not take a group of wizards to determine how to use COTs in non-critical space applications.



Approaches used for manned applications include limited items such as CD-players evaluated for safety to high criticality applications where the COTs hardware is evaluated on a case-by-case basis for the application and commensurate screening and qualification testing.

COTS hardware is successfully implemented in both the International Space Station and Space Shuttle but requires evaluation and modifications for the application.

Screening and qualification of COTs hardware used in critical applications may need to be more extensive and stringent than traditional military screening.

Evaluation for

- Suitability for the application
- Safety
- Reliability and maintainability
- Workmanship