Radiation, Reliability, and Extreme Environment Challenges for JPL Parts Programs

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Introduction

- Overview
- JPL Mission
- Major Projects
- Parts Concerns – Radiation, Reliability, Extreme Environments, etc.
- Approach to Meeting Parts Reliability Requirements
- Reliability and Upscreening Requirements & Capabilities
- Radiation Environments & Design Approaches
- Radiation Testing Capabilities & Concerns

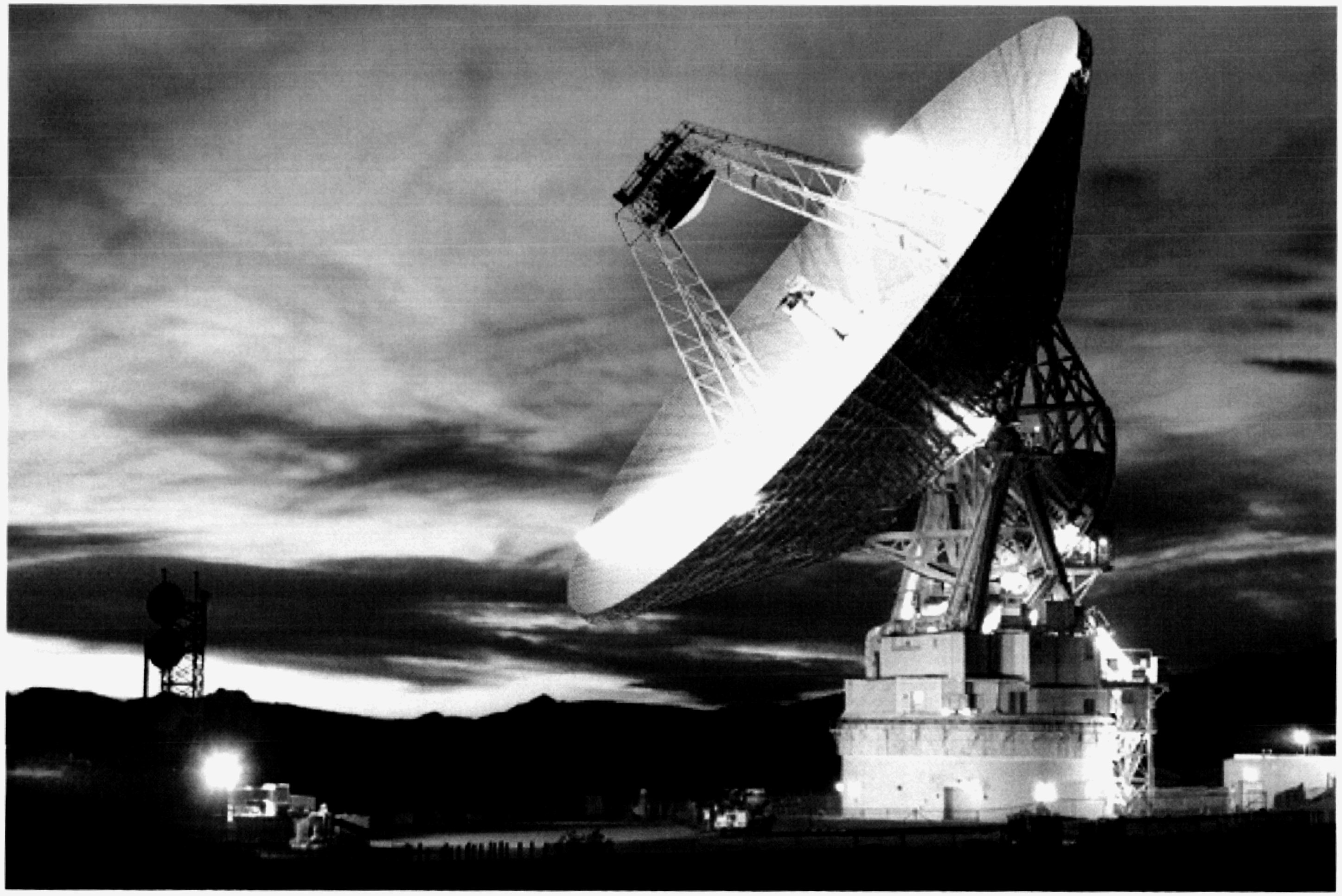
Overview

- Jet Propulsion Laboratory is managed & staffed by the California Institute of Technology under the prime contract with NASA.
  - JPL is a separate operating division of CalTech.
  - JPL facilities are owned by NASA.
    - 177 acres (~0.72 km^2) in Pasadena, CA
    - Nestled against foothills of San Gabriel mountains
    - Couple of miles north of Rose Bowl
- Approx. 5300 employees plus ~700 contract employees
  - Total slightly over 6,000 people

The Laboratory – Pasadena, CA

Deep Space Network

Goldstone, CA (pictured below). Additional sites in Madrid, Spain & Canberra, Australia



JPL's Mission

- Design and build robotic spacecraft for outer space exploration, as well as Earth observation missions

Activities in Support of JPL's Mission

- Maintain spacecraft throughout missions, handle problems if they arise, receive and analyze data from spacecraft, share with world
- Push state of art in development of spacecraft and supporting technologies, as well as strategies of utilizing existing/emerging technologies to meet mission requirements

JPL Projects

- Mars
  - Viking
  - Pathfinder/Sojourner
  - Surveyor
  - Odyssey
  - Explorer, Orbiter programs
- Europa
- Voyagers
- Galileo
- Cassini
- Deep Space 1 & 2
- Ulysses
- Mariners (Mercury, Mars & Venus)
- Magellan (Venus)
- IRAS (Infrared Astronomical Satellite
- Explorer
- Ranger & Surveyor (Moon)
- Genesis
- SIRTF
- Pioneer
- Ranger
- Jason
- CloudSat
- GRACE
- Topex/Poseidon
- Stardust
- Quick Scatterometer
- SeaSat

http://www.jpl.nasa.gov/missions/

Extreme Environments

- Space radiation
  - Cosmic rays
  - Radiation belts
  - Solar flares
- Temperature
  - Low temperature (Martian night, ~-70 to -120°C)
  - High temperature (85-125°C)
- Mission life
  - Few years to few decades

Radiation Environments

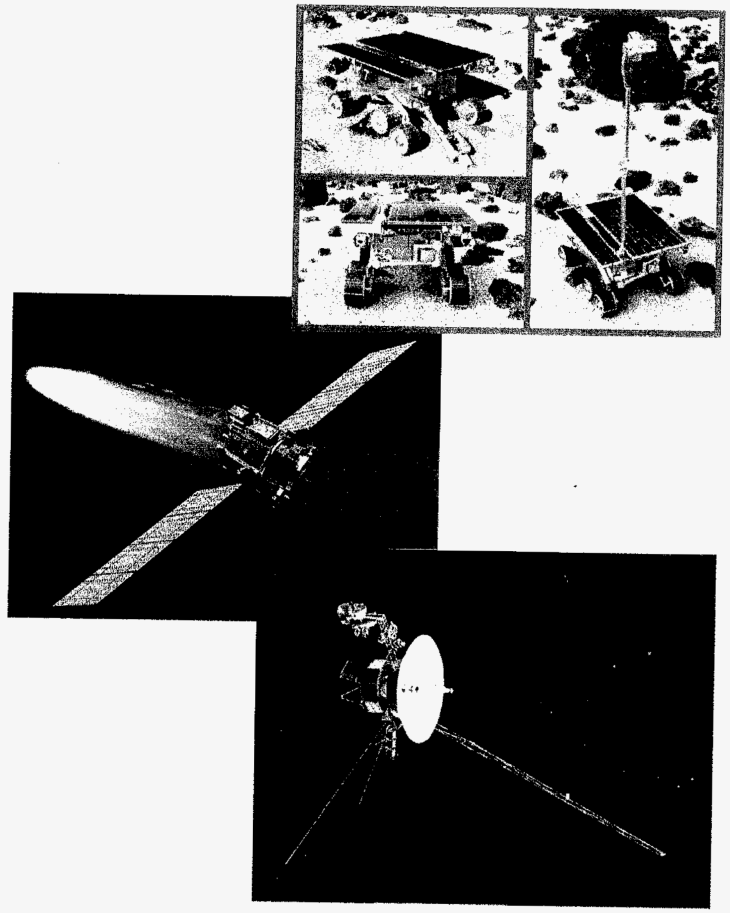
- Space radiation
  - Galactic cosmic rays: heavy, energetic ions (atomic nuclei) cause variety of Single-Event Effects (SEE)
    - Upset (SEU), Latchup (SEL), Burnout (SEB), Functional Interrupt (SEFI), Gate Rupture (SEGR), Multiple-Bit Upsets (MBUs), stuck bits, second breakdown, snapback, etc.
  - Planetary radiation belts: electrons & protons cause total ionizing dose (TID); protons also cause displacement damage (DD)
  - Solar flares: significant output of ions increases particle flux by up to 5 orders of magnitude; also carries significant total dose (mostly protons, ∴ displacement damage, too)
  - On-board Radioisotope Thermoelectric Generators (RTGs)
    - Neutrons, gamma rays
- Mission categories
  - Outer planets (Jupiter to Pluto): Jovian belt dominated
  - Mars, asteroids, comets: cosmic rays, solar wind, & solar flares
  - Earth missions: dominated by Van Allen belts, South Atlantic Anomaly (SAA), & polar areas (vulnerable to flares)
  - Inner planets (Mercury, Venus): dominated by solar proximity

Comparison of Environmental Requirements

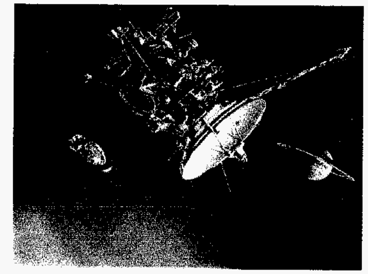
	Natural Space	Strategic Missile
Reliability	High requirements: driven by distance, long life, low build quantity, project cost, inaccessibility for repair	High requirements: driven by security, nuclear surety, long life, life-cycle cost
Temperature	Minimum below MIL spec. (~–70°C): driven by Martian night; maximum varies, but typically ~+85 to +125°C	Minima typically near 0°C (silo or sub); maximum, +125°C
Displacement Damage	10^{10} to 10^{12} protons/cm² (roughly equivalent to ~2.4 x 10^{10} to 2.4 x 10^{12} neutrons/cm²)	Similar for boost, higher for reentry
Total Ionizing Dose	Few kilorads to megarads (waivers allowed if shielding analysis can show lower level, or if more shielding added); ELDRS very strong concern	Depends on shielding: minimum is ~order of magnitude higher; maximum is ~order of magnitude lower (ELDRS concern minor)
Peak Ionizing Dose Rate	Not applicable for natural space (insignificant X rays, gamma rays in space)	Depends on shielding – on the order of 10^{10} to 10^{13} rad/s
Single Event Effects	Strong concern, due to mission duration & no. of COTS parts: requirement of $\leq 10^{-10}$ errors/bit-day & $<10^{-4}$ Latchup/SEB/SEGR per year (waivers allowed if design mitigations used)	Some concern, due to mission nature, but not grave problem, due to hard parts, brief mission (but watch out for SEFI & SET)

Institutional Parts Program

- A minimum parts program applicable to all JPL missions
  - Is based on a minimum of "Level-B" parts program, with some additional tests and evaluations
  - Includes clear criteria for the utilization of COTS and PEMS
  - Targets 5-year mission life (or more, if required by mission)
  - Has radiation tolerance levels set by mission requirements
- Recommend using the best part levels available

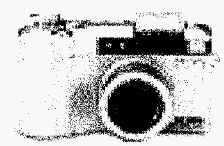


Part Levels



- Class S (recommended for critical and space applications)
  - Microcircuits: NPSL Level 1, QML V
  - Discrete and hybrids: JANS, QML K
  - Passives: ER-S, ESA/SCC Level B

- Class B (recommended for military applications)
  - Microcircuits: NPSL Level 2, QML Q
  - Discrete and hybrids: JANTXV, QML H
  - Passives: ER-R, ESA/SCC Level C



- Commercial (not intended for high-reliability applications)
  - Microcircuits: NPSL Level 3, 883B, QML M, N
  - Discrete and hybrids: JANTX, QML T
  - Passives: ER-P, M, L
  - COTS vendor flow, COTS flow not determined

Institutional Parts Requirements (Quality)

- Class B+ (recommended for most JPL flight applications)
  - Active Devices – Requirements as shown below with addition of Destructive Physical Analysis (DPA on a sample basis), Particle Impact Noise Detection (PIND), and X-Ray screening
    - Microcircuits: NPSL Level 2, QML Q
    - Discrete and hybrids: JANTXV , QML H
    - Plastic Encapsulated Microcircuits (PEMs) per JPL D-19426
    - PEMs
  - Passives: ER-R, ESA/SCC Level C

Part Quality Assurance Provisions

- Classified According to the Following:
  - In-Process
  - Screening (100%)
  - Quality Conformance Inspection
  - Qualification Tests
  - Others (DPA, Hardness, etc.)
- Parts may be Level 1 or Level 2, where Level 1 are strongly preferred for flight- or mission-critical, and Level 2 parts may be used for science instruments and other non-critical equipment.
- Parts not meeting minimum requirements are upscreened:
  - Short-term missions require Groups A & B inspection testing designated in the performance specifications for the part.
  - Long-term missions require Groups A, B, & C inspection testing, and may require more stringent derating curves.
- Parts meeting minimum quality and reliability criteria of standards may be added to the project's parts list.
- Extensive Flight Stores plus Receiving Inspection & Failure Analysis/Disposition

Radiation Hardening Design Approaches

- Use mix of rad-hard parts (RHA levels P through H, most often R), as well as parts with adequate hardness
  - Radiation characterization/lot-acceptance testing performed to determine/assure hardness (TID, DD, & SEE) hardness
- Add local shielding (based on analysis)
  - Required Radiation Design Margin increased from 2 to 3 for locally shielded parts
- Other mitigation schemes (e.g., EDAC, TMR, latchup-circumvention, etc.)
- Trending toward better balanced approach:
  - Smarter, Cost/Quality/Schedule consciousness, Smaller, Best-Value
  - Risks identified, quantified, & balanced

Institutional Parts Requirements (Radiation)

- Total Ionizing Dose (TID)
  - Evaluation on all active parts
  - Based on radiation design factor (RDF) of 2, as indicated in the Project's Environmental Requirements Document (ERD)
- Displacement Damage (DD)
  - Evaluation on all active parts
  - Based on radiation design factor (RDF) of 2, as indicated in the Project's Environmental Requirements Document (ERD)

Institutional Parts Requirements (Radiation, cont'd.)

- Single Event Effects (SEE)
  - Single Event Latchup (SEL)
    - No latchup to LET of 75 MeV-cm^2/mg, or
    - Device latchup probability of 10^{-4}/year in mission environment for devices with latchup thresholds between 35 MeV-cm^2/mg and 75 MeV-cm^2/mg
  - Single Event Upset (SEU)
    - No upsets to LET of 75 MeV-cm^2/mg, or
    - Bit error rate of 10^{-10} in galactic cosmic ray environment (GCR), or
    - Verification that part upset rate is compatible with system upset rate requirement
  - Single Event Burnout (SEB) or Gate Rupture (SEGR)
    - Derate to 75% of survival voltage (V_{BE} & V_{DS} for SEB, V_{DS} for SEGR)

Radiation Shielding

- Typical mission total dose requirement based on depth-dose shielding curve at nominal shielding thickness (i.e., 0.1" Al)
  - Radiation Design Factor of 2 required (99/90 confidence)
- Parts not meeting this level require detailed shielding analysis and waiver
- Analysis considers all known, major masses in spacecraft as well as circuit boards, etc. inside a box
  - Slab sector or ray trace analyses used
- Shielding may be increased at spacecraft level, box level, or part level to meet requirements (although waiver is required)
  - Radiation Design Factor of 3 required for locally shielded parts

Digital Parts

- High density SRAMs & DRAMs (64M & 256M types tested, respectively)
- High density Flash memories (256M parts tested)
  - Great interest in other Non-Volatile Memory developments and test results
- High speed processors (e.g., PowerPC750)
- FPGAs (including RAM/Flash-based types) preferred over ASICs, due to build low quantities plus reconfiguration capability

Power Converters

- Modular (hybrid) converters
  - Typically, 28V to 5V, 3.3V, ±5, etc.
  - Powers ranging from 1.5 W to 105 W

Linear ICs

- Typical functions
  - Low-dropout voltage regulators, 12-14 bit converters, phase-locked loops, optocouplers, VCOs, etc.
- Prefer vendors offering Radiation Hardness Assured parts, or those whose parts have known, acceptable hardness
  - Minimize costs of testing unknown parts

Discrete Parts

- Power MOSFETs, bipolar transistors, JFETs, GaAs FETs, and general purpose diodes
  - JPL/NASA-heritage parts & other rad-hard parts wherever feasible

JPL Test Capabilities

- Radiation Effects group staff of 20
- Two Cobalt-60 sources on-Lab, Californium source, & laser
  - Co-60 cells in use almost continually
    - High Dose Rate (~78 rads/sec)
    - Low Dose Rate (1 mrad/sec to 1 rad/sec)
- Single-Event testing performed by JPL at Brookhaven, Texas A&M, Indiana, UC Davis (plus Berkeley in CY02)
  - SEE testing performed roughly every few weeks
- About 100 part tests per year (~50 TID/DD & 50 SEE)

JPL Test Concerns

- Total Ionizing Dose
  - ELDRS (Enhanced Low Dose Rate Sensitivity) for bipolars
  - Researching accelerated Low Dose Rate testing methods
  - Test biased & unbiased (missions use parts both ways)
  - Temperature extremes considered
  - Displacement damage (optos, fiber devices, references, other precision linears)
- SEE
  - Testing for SEU, multiple bit upsets, stuck bits, upset of complex or hidden modes, functional interrupts, latchup, Single-Event Burnout or Gate Rupture (SEB/SEGR), etc.
  - Temperature, bias effects

Summary

- JPL launches several missions per year
  - Allows continual improvements of knowledge bases due to constant need for addressing new designs & new parts
  - Requirements obviously not the same as strategic needs
    - Vary from one mission to another
  - However, many requirements are similar to one degree or another, therefore information exchange beneficial
- Extreme environments include radiation, extreme temperatures, high reliability requirements
  - Supporting Space Parts Working Group (SPWG) & SHPWG, as invited - sharing data, experiences, & lessons learned
- Providing funding as available for development of hard parts needed to support future space technology needs
- Improving skills/knowledge base to design & build better spacecraft for exploration of universe

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