Goddard Space
Flight Center

National Aeronautics and
Space Administration

APPLIED ENGINEERING AND TECHNOLOGY DIRECTORATE
NASA GODDARD SPACE FLIGHT CENTER

NASA Presentation to NASDA Parts Engineering Experiences, Philosophies, and Trends

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Associate Head

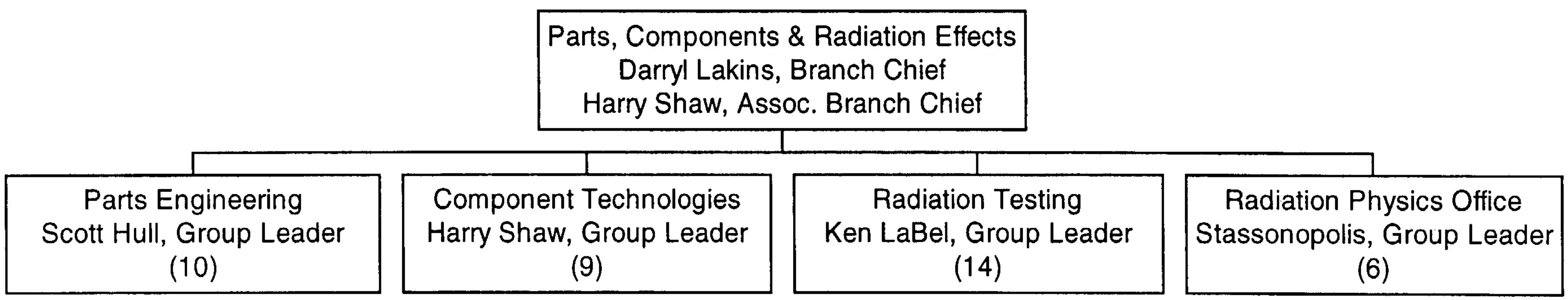
Component Technologies and Radiation Effects Branch

October 25, 2000

Overview

- Introduction
- COTS evaluation of circuit boards for Spartan 251 Program
- ICESAT Parts Program-case study
- QPL/QML Situation with NASA
- New NASA initiatives in Parts Engineering

Organization



Group Missions

- Parts Engineering: Flight part selection, screening and procurement, qualification policy, parts advisories, source inspections
- Component Technologies: Advance understanding of reliability of new and emerging parts and packaging technologies for use in new flight hardware
- Radiation Testing: Quantify radiation tolerance of existing and new parts for flight projects, study radiation tolerance of new and emerging technologies and radiation hardening techniques
- Radiation Physics Office: Provide flight programs with information about the radiation environment, develop methods, through simulation and flight experiments, for predicting radiation environments

Component Technologies (cont.)

Continued Development of Core Expertise

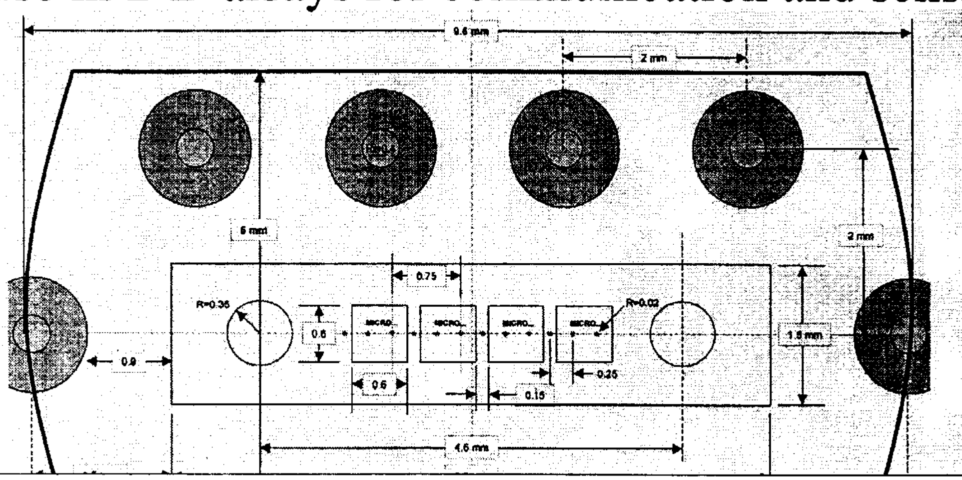
- Investigations of new parts and materials which will enable electronics miniaturization or increased performance
- Development of new, miniaturized packaging systems
- Exploration of detector technologies and components and materials required to support them
- Participate in RFI's and AO's when possible
- Development of assessment methods
- New technology development in fiber lasers

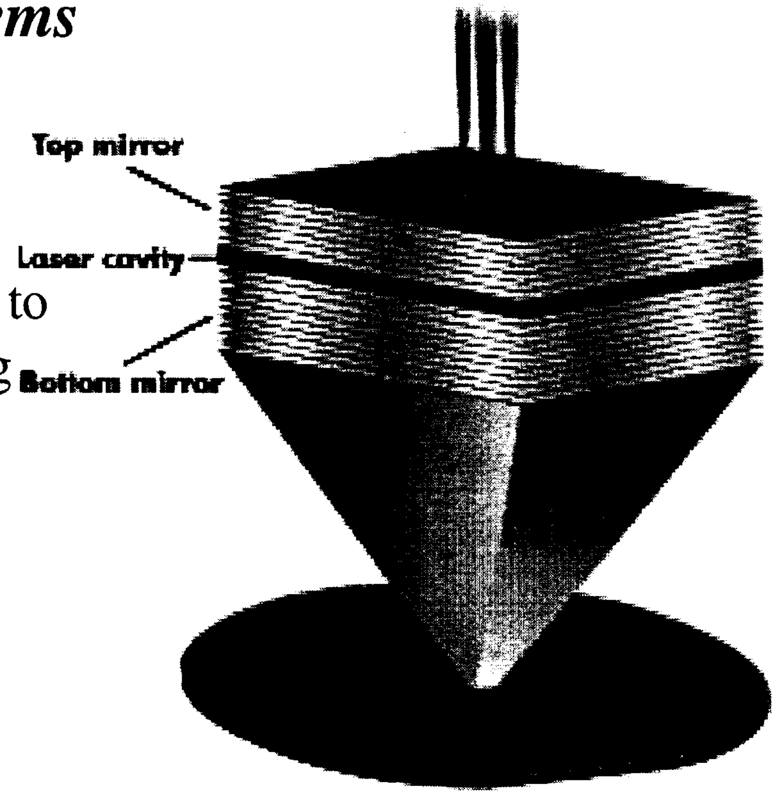
http://spaceflightnow.com/news/n0008/26fiberoptics/

Using Advanced Materials, Interconnect and Components to Enable New Systems

VCSELs on Diamond

Why VCSELs? Very small, high speed, low power consumption whose geometry lends itself to use in 2-D arrays for communication and sensing



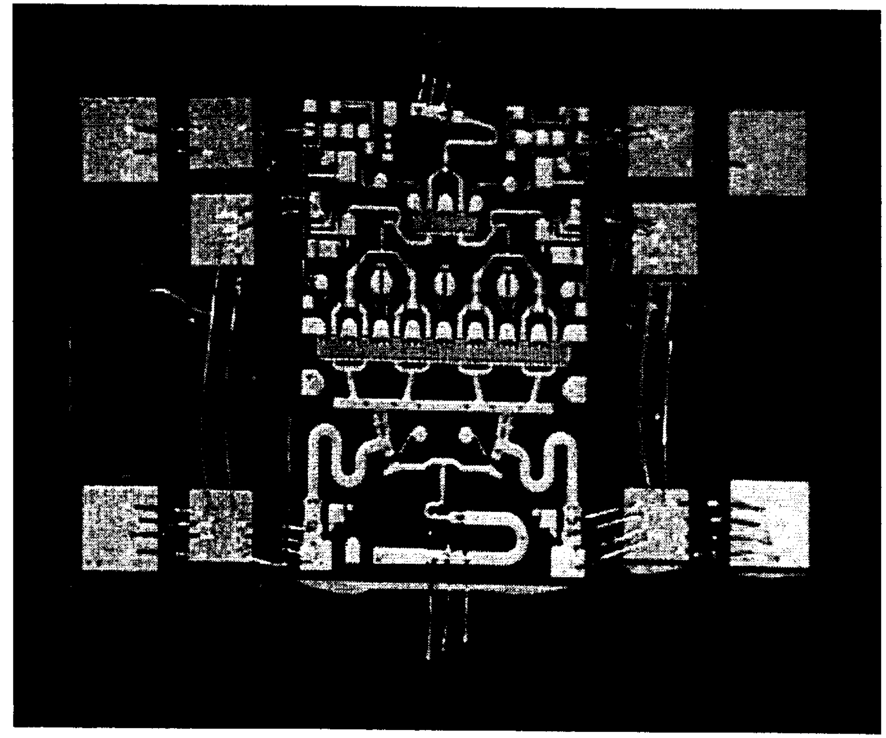


Design and procure diamond substrates for transistor packages

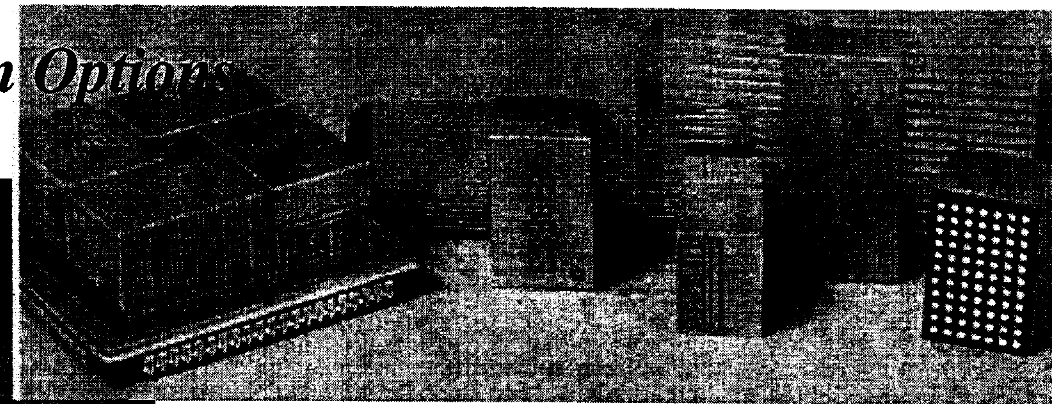
- Terminate multi-fiber connector to package
- Run devices at increasing speed to show advantage of high thermal conductivity in the substrate
- Measure performance over temperature

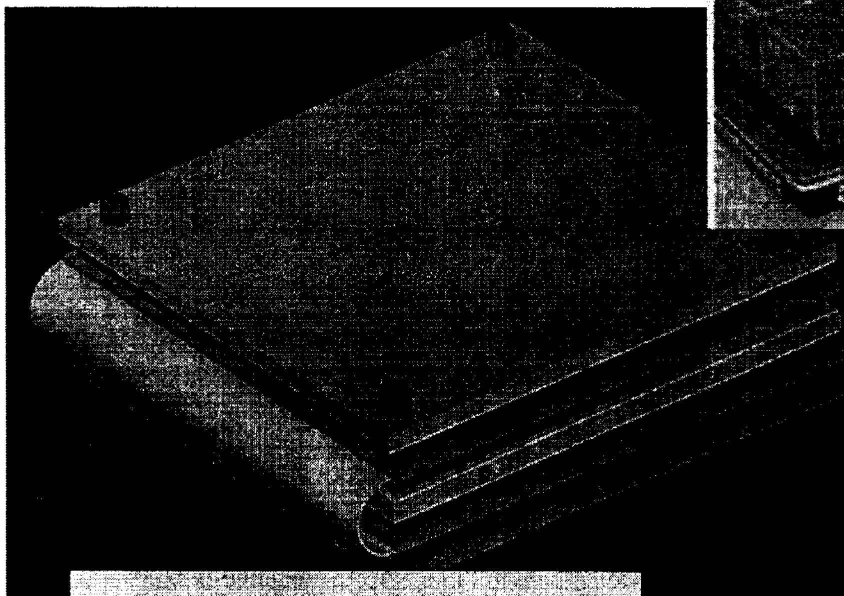
VCSEL on CVD Diamond

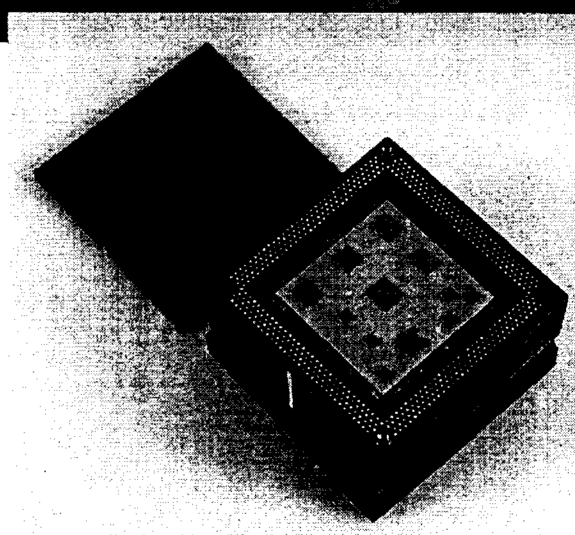
X-band GaAs MMIC on CVD Diamond



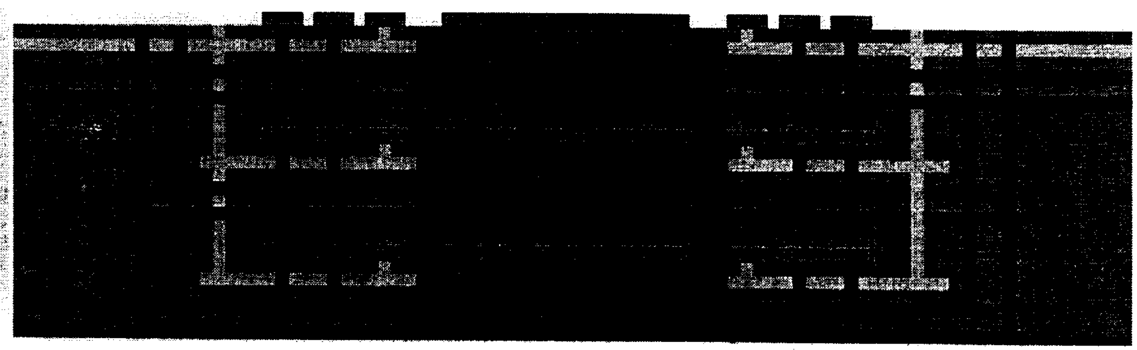
Evaluating Miniaturization Options



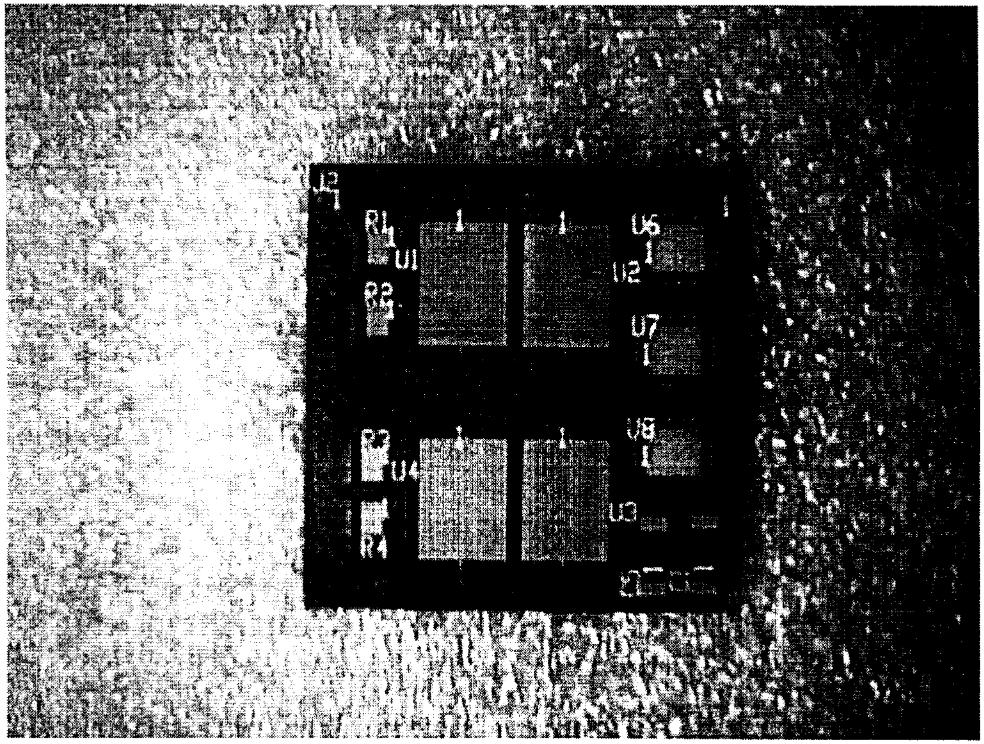




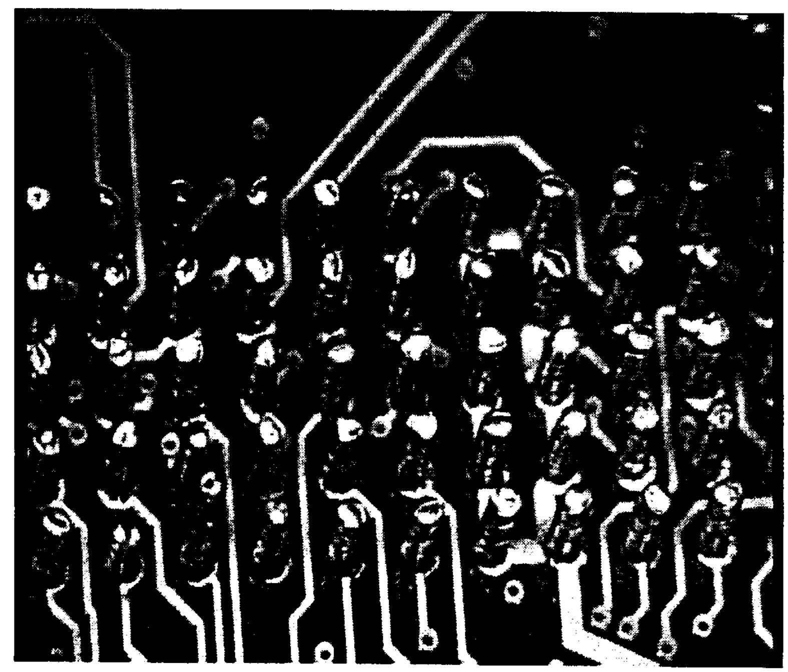
- Volume
- Packages, Dice
- Power Dissipation
- Mechanical/Thermal stress
- Radiation shielding
- Cost, Schedule



Laser Repairable Chip on Board



Column Grid Array
for 3D Packaging



Assurance of COTS Boards for Space Flight

NASA GSFC/Swales Aerospace
Technology Validation Assurance Team

Dr. Michele Gates, Dr. Henning Leidecker, Harry Shaw
NASA Goddard Space Flight Center

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Norma Lee Todd, Dr. Mark Fan
Swales Aerospace

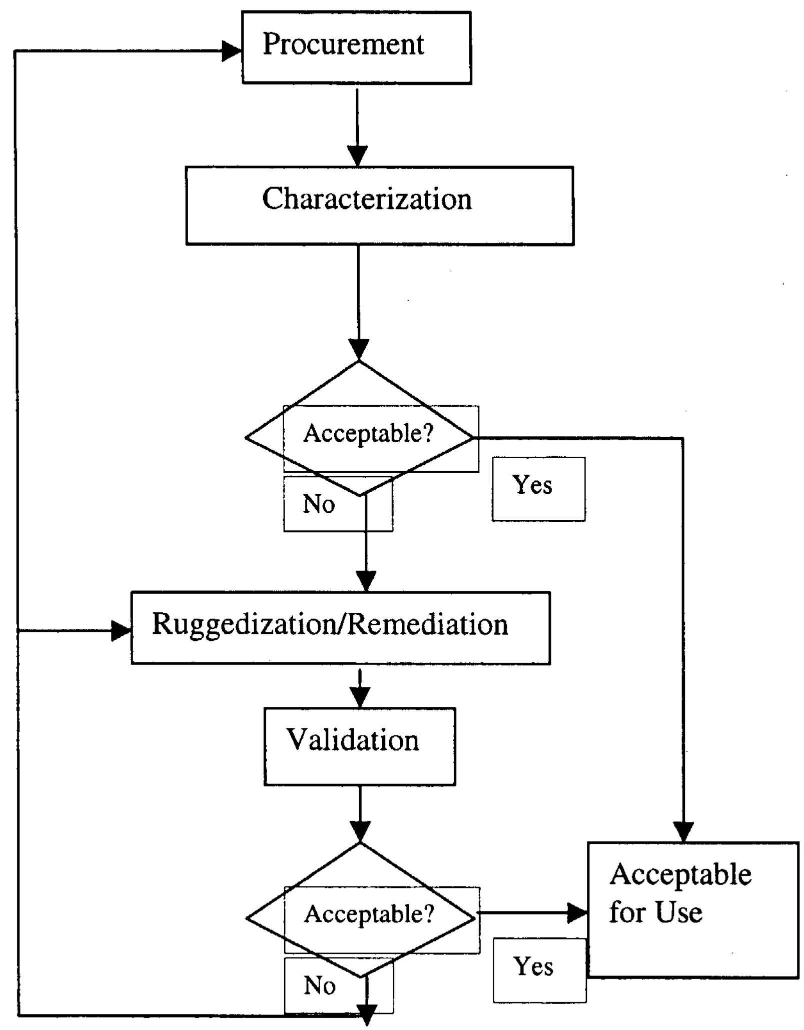
Spartan 251 COTS Goals

- Fast Procurement: Multiple vendors, Standard specifications/performance
- Fast Integration: Standard footprint, Benchtop software

Reliability Goals & Realities

- Increase system reliability by:
  - eliminating short term failures
  - reducing number of mid- or long-term failure causing flaws
  - delaying flaws' growth to failure
- COTS are not reliable on the ground without thermal and mechanical augmentation. Board quality may be unknown.
- Worst case conditions are software driven and application specific

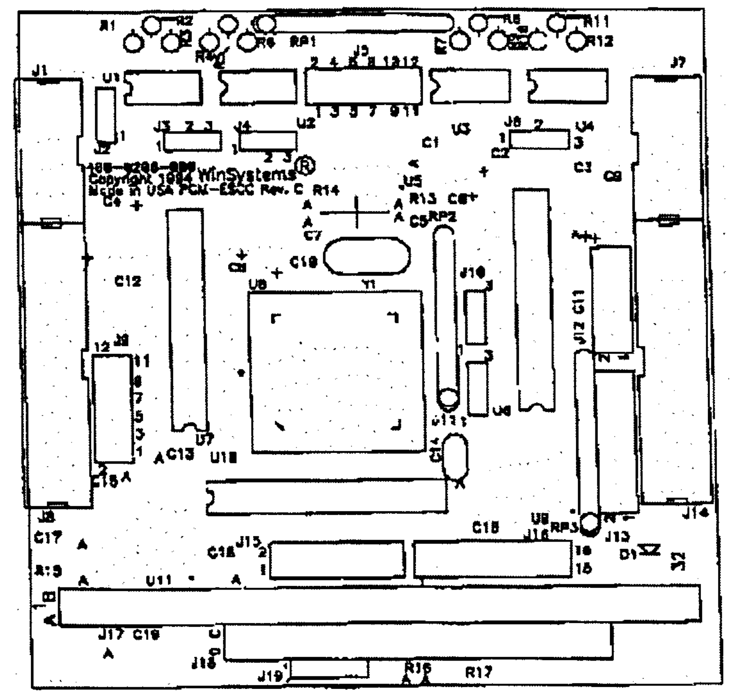
Board Type	Part Number	Manufacturer	Function
6U Processors	CR6400053NBC	OR Industrial Computers	Compac PCI Pentium Board
6U Processors	CTM6	OR Industrial Computers	I/O Transition Module
6U Processors	ZT5510C4R3P3S1M3	Ziatech	CPCI Processor Board
3U Processors	CPCI-3603 (103095)	Force	POWERCORE/CPCI Processor board
3U Processors	CPCI-3740 (104912)	Force	POWERCORE/CPCI Processor board (233MHz)
Memory	104949	Force	POWERCORE/CPCI memory board
IP Carriers	CPCI-200-FP	SBS Greenspring	6U IP Carrier Board
IP Carriers	CPCI-IPC	Alphi Technology	3U IP Carrier board
IP Carriers	CPCI-SIP	Alphi Technology	3U IP Carrier board
Analog Input	IP-320	Acromag	Analog Input
Analog Output	IP-220-16	Alphi Technology	16 channel Analog Output
Digital I/O	IP-UNIDIG-E-48	SBS Greenspring	DIGITAL I/O
Digital I/O	IP-UNIDIG-HV-8I16O	SBS Greenspring	DIGITAL I/O
Digital I/O	IP-UNIDIG-D	SBS Greenspring	DIGITAL I/O
Digital I/O	IP-OPTO DRIVER	SBS Greenspring	DIGITAL I/O Optical Driver
Digital I/O	IP-445	Acromag	32 Channel, bus isolated Digital Output
Digital I/O	IP-440-1	Acromag	32 Channel, bus isolated Digital I/O +/- 4 to +/- 18 Vdc
Serial I/O	SCC-04B	Alphi Technology	Quad RS422 serial interface
Serial I/O	IP-Serial	SBS Greenspring	Serial I/O
Serial I/O	MP-Serial	SBS Greenspring	Synch/Asynch Data Com
Thermistor IF	IP-Thermistor	SBS Greenspring	Thermistor card



COTS Insertion Flow

Start with Procurement:

- ask for parts lists
- ask for manufacturing lot traceability
  (or consecutive serial numbers)
- ask about return policies
- ask about materials used
- ESD control
- procure extra units for destructive tests and spares
- begin screened stores stock system



Can the manufacturer tell you?

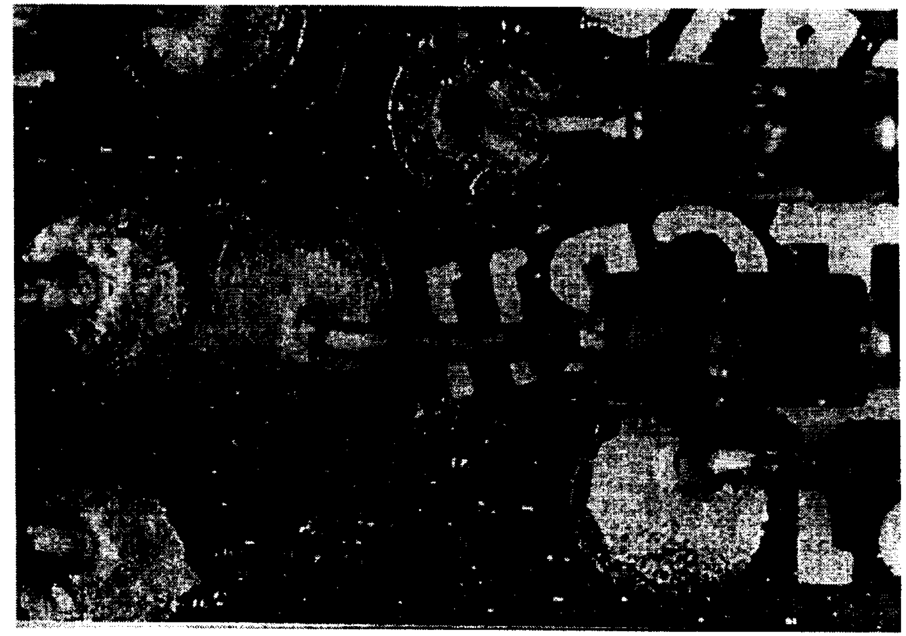
"we **cannot guarantee** that the components on these boards will have been manufactured in the same lot code or even in **the same process technology**......"

"...**mounting details and electrical connections** can be furnished at an appropriate charge."

"Consecutive serial numbers ... can be supplied for a 10% price adder per unit plus a **16 week lead time**..."

Visual Inspection

- Jumper wires not glued down, no insulation
- Hardware covered by different design revisions
- Solvent/cleaner residue
- Heat damage (possibly from rework)
- Need to carefully inspect traces and solder joints for evidence of the lack of quality control



Characterization

To understand the ability of the "as received" units to withstand the intended application and environment and to understand the engineering challenges associated with providing risk mitigation paths

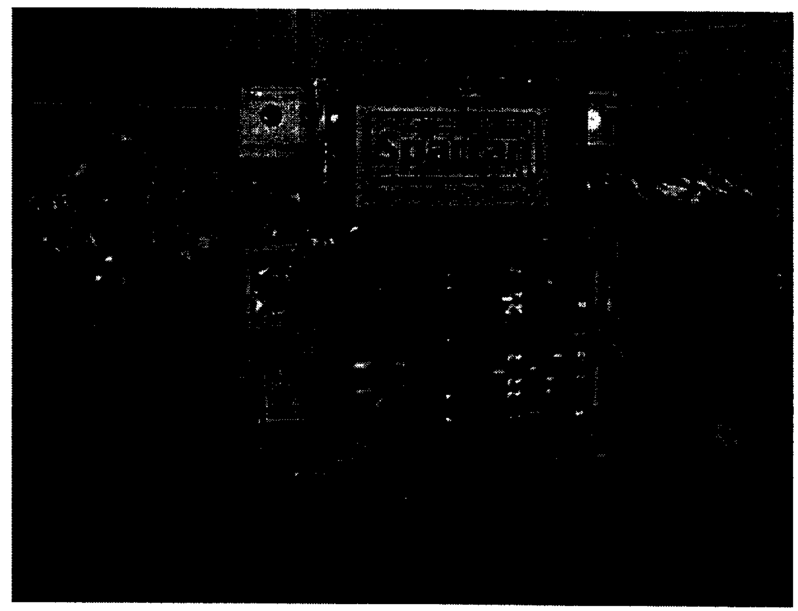
Radiation Thermal Mechanical

Contamination Electrical

Radiation Testing

- Destructive and non-destructive testing
- Environment Assessment & Total Dose expected
- Mission/application specific test procedures
- Proton Testing - SEE & Cumulative Dose
- 1 martyr board , high proton fluence - statistics on SEEs of Board
- Flight board, low fluence - confidence that devices on flight board respond similarly to proton environment as high fluence tested board.

Board-level Testing Issues



- Device characterization challenges
    - How is each device being tested?
    - How are errors being monitored?
    - How are errors being captured?
- Monitoring current for latchup detection
- Application sensitivity
- Devices on both sides of boards
- Card density vs. beam profile
    - Probably hitting nearby devices on each side

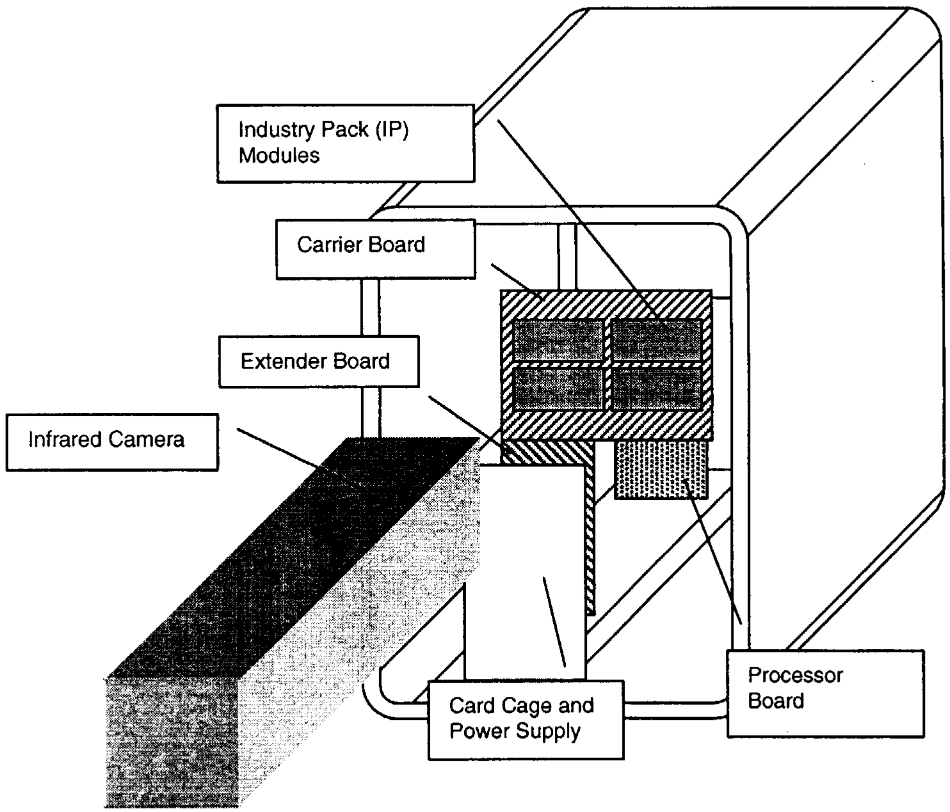
Thermal Characterization

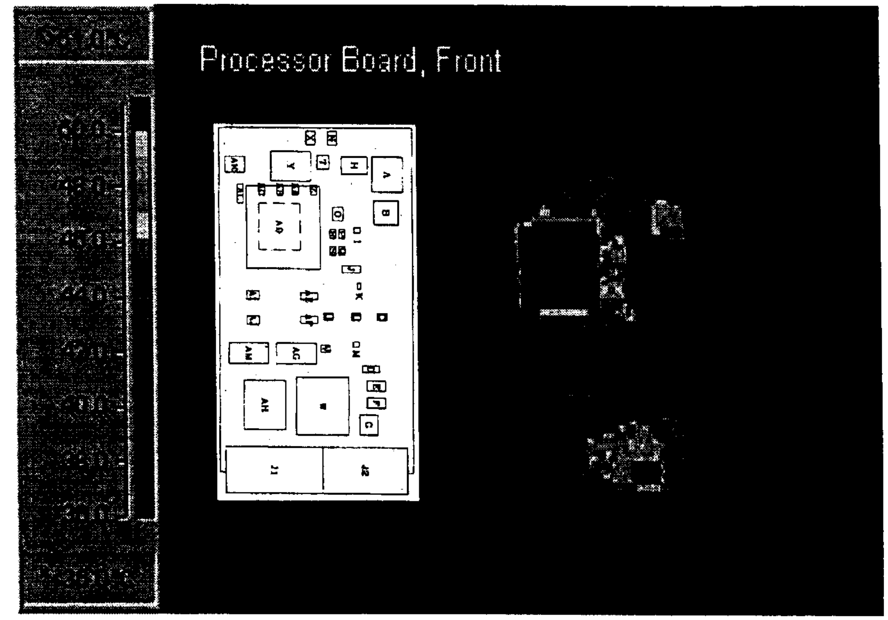
- Determine the heat producing parts through specifications, through testing with thermocouples or by using IR imaging.
- Use thermal models to identify sufficiency of existing thermal paths. Identify the system's thermal "ground"
- Identify the need for diffusion, conduction and convection mechanisms when designing thermal management solutions.

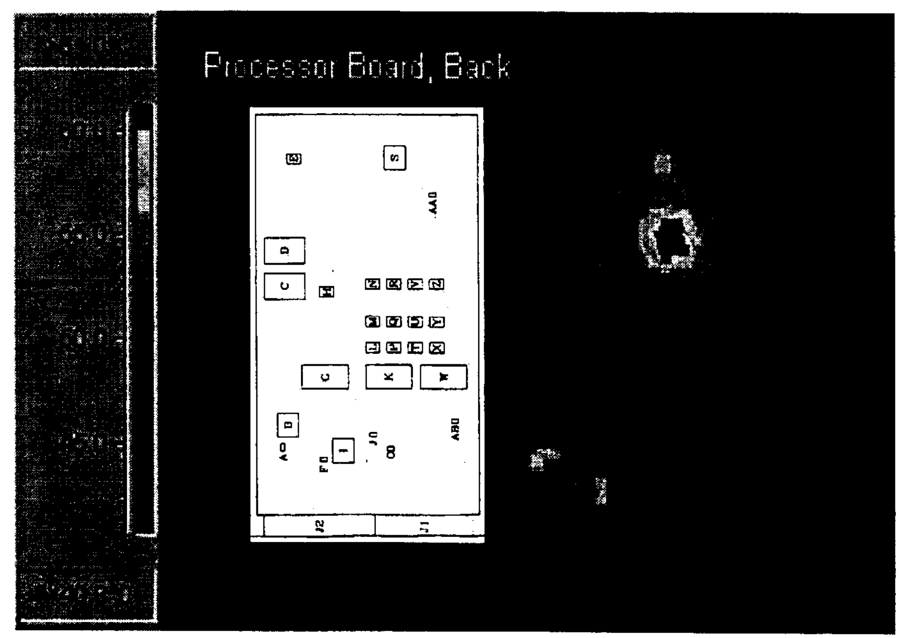
  Solutions may include, copper heat straps,
  CVD diamond, fluid embedding

IR Imaging Approach

- Understand emmisivity relationships (mapping, software)
- Controlled ambient environment
- Board by board survey for thermal couple placement
- Monitor currents
- Configuration Imaging
- Feed back data for modeling


Industry Pack (IP) Modules
Carrier Board
Extender Board
Infrared Camera
Card Cage and Power Supply
Processor Board


Processor Board, Front

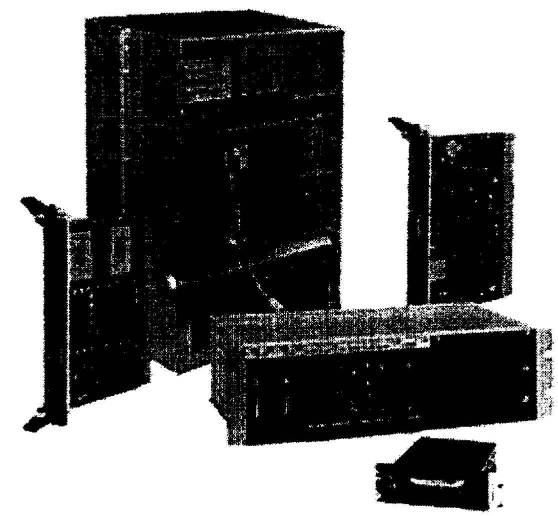

Processor Board, Back

THERMAL MARGINS RANKED

Board	Part ID	Part #	Manufacturer	Description	Max Operating Temp (°C)	Thermocouple Data for Flight Configuration (°C)	Thermal Margin At 22.5°C Ambient	Assumed Thermal Margin At 60°C Ambient (°C)
Processor, Front	G	MPC970	Motorola	PLL Clock Driver	70	61.44	8.56	-28.94
UniDig-D	U31	SP485	Sipex	Lo Pwr Half Duplex RS-485 Xciever	70	59.53	10.47	-27.03
UniDig-D	U23	SP485	Sipex	Lo Pwr Half Duplex RS-485 Xciever	70	56.75	13.25	-24.25
UniDig-D	U20	SP485	Sipex	Lo Pwr Half Duplex RS-485 Xciever	70	54.82	15.18	-22.32
UniDig-D	U27	SP485	Sipex	Lo Pwr Half Duplex RS-485 Xciever	70	52.4	17.6	-19.9
SCC-04BH	U12	SN75174	TI	Quad Diff Line Driver	70	50.19	19.81	-17.69
320 Module	U6	PGA203KP	Burr Brown	Instrumentation Amp	70	48.98	21.02	-16.48
320 Module	U10	74ALS990	TI	D-type Transpar. Read Ltch	70	48.97	21.03	-16.47
320 Module	U9	74ALS990	TI	D-type Transpar. Read Ltch	70	48.42	21.58	-15.92
220-16 Module	U1	DAC4813AP	Burr Brown	Quad 12 Bit D/A Converter	85	60.82	24.18	-13.32
220-16 Module	U2	DAC4813AP	Burr Brown	Quad 12 Bit D/A Converter	85	60.56	24.44	-13.06
220-16 Module	U4	DAC4813AP	Burr Brown	Quad 12 Bit D/A Converter	85	60.18	24.82	-12.68
Processor, Front	AD	XPC603PRX166LE	Motorola	PowerPC 603e uProcessor	85	59.08	25.92	-11.58
220-16 Module	U3	DAC4813AP	Burr Brown	Quad 12 Bit D/A Converter	85	57.68	27.32	-10.18
Processor, Back	S	PLDE 2032-135L	Could not identify	Could not identify	N/Avail	54.46	Not Available	Not Available
320 Module	U12	5025-538A	Could not identify	Could not identify	N/Avail	53.96	Not Available	Not Available
Processor, Back	I	PLDE 1016-125LT	Could not identify	Could not identify	N/Avail	53.6	Not Available	Not Available
Processor, Back	B	PLDE 2032-135L	Could not identify	Could not identify	N/Avail	53.37	Not Available	Not Available
220-16 Module	U6	5024-512A	Could not identify	Could not identify	N/Avail	51.59	Not Available	Not Available
320 Module	U11	5025-537A	Could not identify	Could not identify	N/Avail	51.5	Not Available	Not Available
6U Carrier	U1	PLX PC19060	Could not identify	Could not identify	N/Avail	51.29	Not Available	Not Available
Processor, Front	W	82371	Could not identify	Could not identify	N/Avail	50.3	Not Available	Not Available

Shock and Vibration

- Know your launch vehicle's qualification level requirements
- Consider the placement of the parts and the clamping mechanisms
    - 6u vs 3U footprint
    - mezzanine cards
    - large pin-out flat-packs
    - connectors
- Characterize a "martyr" board for displacement and resonant frequencies
- Ruggedize the boards with stiffeners, staking, bolted down mezzanine cards, board edge clamping, etc.



Contamination

Sources can be the connectors, plastic packages, cleaner residues, cabling

Re-evaluate the standard outgassing requirement's applicability for the project

Configuration testing can be done using SP-R-0022

Electrical

Functionality and Power Consumption - Application driven

Progress with Spartan 250 Boards

Procurement - Finished

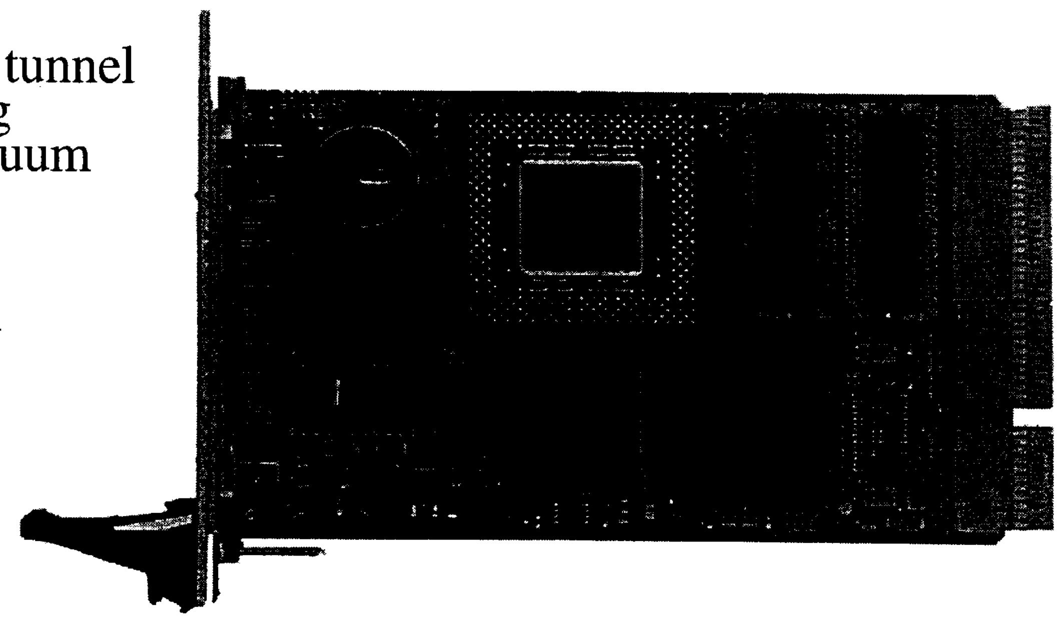
Characterization - still need to review contamination issues

Ruggedization - tiger team coming to a solution for hot parts. Modeling of solution in progress.

Methodology Plan in Draft: *http://misspiggy.gsfc.nasa.gov/tva/cots/insertplan.htm*

IR imaging/low speed wind tunnel in progress for predicting thermal behaviors in vacuum

Looking at the use of CVD diamond for remediation



Conclusions

- Each assembly must be considered an individual
- Testing must be performed to limits defined by the application
- Worst case operational modes must be defined by the application software
- COTS Assemblies must be considered a Part
- Much more work must be done to understand how to measure thermal and mechanical behavior at the assembly level
- COTS buys schedule, not necessarily reduced cost

Peer Review
for
ICESat GPS Flight Receivers
EEE Parts

28 August 2000

Prepared by: Code 303.0

Dr. James Howard, Jackson and Tull
Bruce Meinhold, Jackson and Tull

Chairman: Harry Shaw

Purpose

- Assess the adequacy of EEE parts test and evaluation program to satisfy minimum ICESat mission requirements.
  - Review ICESat mission quality and radiation requirements for EEE parts.
  - Review parts and radiation test plans.
  - Review electrical and radiation test results.
  - Review pertinent part failures.
  - Identify remaining open issues/actions required.

GSFC GPS Receiver Engineering Support Team

- **Jackson and Tull**: Jim Howard, Song Jung, Bruce Meinhold, Noman Siddiqi
- **Code 562**: Scott Hull, Greg Rose, Robert Reed, Janet Barth
- **SGT**: George Gee
- **Code 303**: Ron Kolecki
- **Code 302**: Walt Thomas
- **Test Support**: Unisys-Lanham, JHU/APL

ICESat Mission Requirements

- Measure decadal variation of ice sheet thickness, altitude and thickness of clouds, height of vegetation, topography, and ocean surface and sea ice using LASER altimeter.
- Three year mission with five year expendables.
- 311-INST-001 Level 2 parts program.
- 10 krad (Si) - 100 mils Al TID environment (5 yr).
- Latchup immune components desired.
- No destructive single event effects.

Blackjack GPS Receiver Background

- Advanced JPL design of a COTS GPS Receiver for spaceflight.
- JPL controlled and directed assembly processes.
- Spectrum Astro performed the majority of assembly operations for ICESat Receivers.
- JPL restricted part “upgrades” to exact form, fit, and function equivalent only.

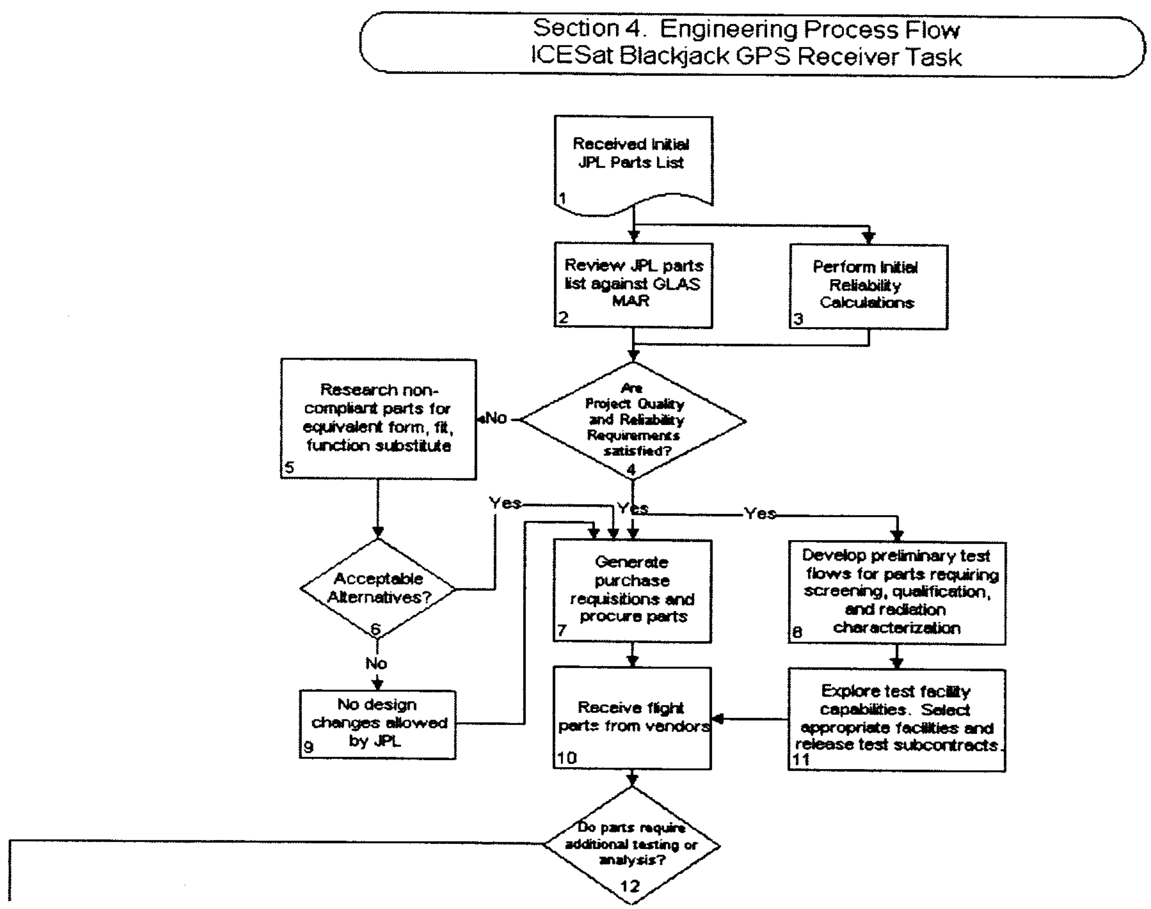
ICESat GPS Receiver Parts Upgrade Implementation Plan

- Replace EEE parts on JPL parts list with equivalent, high reliability, radiation hardened, Level 2 devices, wherever form, fit, and function limitation could be met.
  - GSFC PPL-21, MIL-STD-975, NASA Parts Selection List (NPSL), Military Specifications, and compliant Manufacturer High Reliability flows.
- Approximately 17% of the active devices and 66% of the passive devices were replaced with high reliability equivalents.

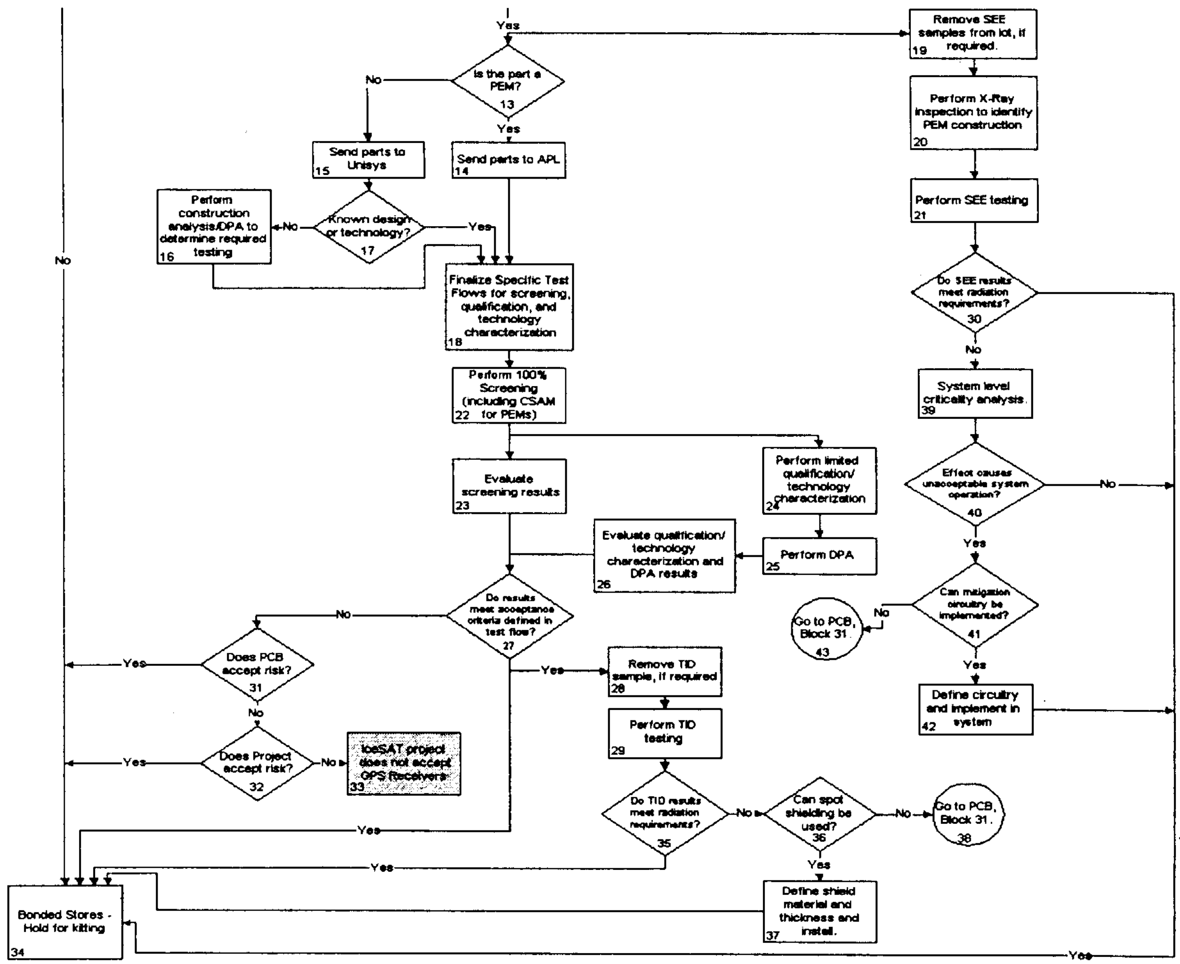
ICESat GPS Receiver Parts Upgrade Implementation Plan

- Screen and qualify remaining commercial part lots
  - Passive device screening and qualification test plans (including sample sizes) were based on nearest applicable military specifications. Screening included burn-in or conditioning as applicable.
  - Screening and technology characterization test flows for Plastic Encapsulated Microcircuits (PEM) were based on MIL-PRF-38535 and GSFC PEM Guidelines. Screening included 100% CSAM; 250 hour HAST for technology characterization.

Parts Engineering Process Flow



Parts Engineering Process Flow



Parts Screening Summary

- Of the 155 total EEE part types, 119 required screening.
- 104/105 completed required screening successfully.
  - 1/105 failed final electrical DF (Capacitor, ceramic). Determined to be test equipment error.
  - Test facility problems, ongoing parts list changes, and parts availability problems prevented fourteen (14) part types from receiving any testing.
    - ASIC, RF devices (filters, mixers, dividers, hybrid amplifiers), resistor networks.

Parts Screening Summary

- No lot failed a final electrical PDA limit of 5% (Class S requirement).
  - For PEM devices, majority of fallout (which was low) occurred at initial electrical and visual/mechanical.
- Time/temperature regression was not followed.
  - JPL concern regarding overstress of PEM devices.
  - Lack of vendor support made determination of upper operational temperature limit difficult.
  - Compliant burn-in times, with reduced burn-in temperatures, were very large.

Qualification/Technology Characterization Summary

- Of the 155 total EEE part types, 93 required qualification or technology characterization.
  - For PEM devices, technology characterization was determined to be a more effective indicator of reliability, and was performed in lieu of "conventional" qualification (i.e. 1000 hour life test).
- 76/93 completed qualification/technology characterization successfully.
  - 3/93 exhibited lot failure at final electrical (Capacitors, ceramic). Determined to be test equipment error.

Destructive Physical Analysis (DPA)/Construction Analysis (CA) Summary

- Of the 155 total EEE part types, 50 required DPA or CA.
  - For PEM devices, DPA was placed after completion of technology characterization, to get a “worst case” look at the device.
- 9/50 completed DPA/CA successfully.
  - 17/50 failed DPA/CA.
  - 4/50 did not receive DPA/CA due lack of available samples or late parts list changes.
  - 20/50 did not receive DPA/CA due to cost/schedule overruns at test facility.

Part Issues

- Significant DPA Failures
  - Interpoint EMI filters
    - Loose particles determined to be Alumina flakes
      - All parts PIND screened; passing parts accepted
  - Multiple lots, Ceramic, low voltage capacitors
    - Failed dielectric thickness requirements per MIL-PRF-123.
      - All lot samples successfully completed Humidity Steady State Low Voltage testing per MIL-PRF-123.
  - RF Power Amplifier
    - 1/5 failed for delamination of gold backside plating
      - Part remained firmly attached (sample passed die shear)
      - Temperature excursions during mission life are minimal

Part issues (continued)

- DPA Failures (continued)
  - Lark RF Filters
    - Filters found to use low melting point (+183C) solder in their construction.
      - SAI informed of the low temperature solder and advised to use appropriate assembly processes.
  - Hybrid Phase Splitter
    - Capacitive elements showed cracking indicative of thermal overstress
      - Capacitor specialist review determined no further degradation was expected.
  - Due to lack of up-to-date BOM, many lots which failed DPA were designed out of flight system.

Part issues (continued)

- RF Component Issues (General)
  - Commercial grade components from commercial suppliers were only options.
  - SAI performed electrical pre-screening of the flight ceramic RF filters, prior to installation, in order to ensure adequate circuit performance margin.

Parts Summary and Recommendations

- Summary
  - All lots passed Class S level PDA requirement of 5%, post burn-in/conditioning.
  - All plastic encapsulated parts were subjected to 100% CSAM; all questionable flight parts were discarded.
    - 453 Devices evaluated with 32 rejects
  - No lots failed qualification or technology characterization due to manufacturing/reliability defect.
  - Low voltage ceramic capacitors which failed DPA for dielectric thickness passed Humidity Steady State Low Voltage (HSSLV) sample testing.

Parts Summary and Recommendations

- Summary (continued)
  - Only one part failed during assembly testing (FLASH Memory).
    - Parts received thermal shock only, and were not fully screened (or DPA'd) prior to installation in assembly, due to test facility schedule problems.
  - DPA was not performed on any PEM device.
    - DPA was scheduled post-HAST, for "worst case" look.
    - Test facility schedule and cost issues caused cancellation of planned DPA.

Parts Summary and Recommendations

- Multiple deviations from Grade 2 EEE parts plan. However,
  - On-orbit environment is benign (very few temperature cycles during mission life (~3), +0°C - +33°C worst case).
  - To date, flight receiver testing has precipitated only one part failure.
  - To date, both flight receivers have seen one thermal vac cycle and multiple temperature cycles without failure.
  - To date, each flight receiver has operated failure free for thousands of hours.

QPL/QML Situation with NASA

Current situation

- Resource limitations make it difficult to fully participate in reviews and updates to military specifications such as MIL-S-19500 and MIL-PRF-38535
- NASA still participates where possible on DSCC audits and JEDEC coordination meetings
- Additional resources from the NEPAG are expected to help
- Regardless of NASA/DoD action QPL/QML sources of supply are expected to continue to diminish, especially for microcircuits and semiconductors

NASA EEE Parts Assurance Group
NEPAG

- New NASA Code Q Initiative in Parts Engineering
- Improving parts management to address new COTS environment
- Greater Coordination of Parts Engineering issues between NASA Centers
- Automating procurement related tasks to maximize application of engineers to engineering problems

Leveraging Gains from a Strong and Rigorous MIL-Spec System

- Defined performance characteristics
- Built in design margins for reliability assurance
- Form, fit, function interchangeability between manufactures
- part number specific, standard parts lists by part type (QPL)
- low probability of infant mortals in flight lot

COTS Impact

- Competing with all other flight projects and commercial industry for limited stocks
- Project turn-around times cannot absorb retrofitting to replace bad parts
- Obsolescence can impact designs
- No time for qualification
- More diverse technologies than previously available through the QPL system

Resulting Pressures on Parts Engineering

- Focus turns to procurement/delivery issues
- Reliability margins are reduced as a replacement for some qualification testing
- "Heritage data" is pursued as a way around qualification testing
- Box level testing is pursued - the use of COTS boards is pursued.

Join Parts Engineering with R&D Investment Activities

- We hope to invest in look-ahead activities such as vendor and market monitoring to track mergers and product changes which will impact part availability
- Identify risk areas for COTS parts
- Provide tools which can capture and build part qualification/use histories that are quantitative enough to assess their “heritage”applicabilty