Parts Selection for Space Systems – An Overview and Radiation Perspective

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Outline

- The Trade Space Involved with Part Selection
- Classifying Parts from a Radiation Perspective
  - Guaranteed
  - Existing Ground Data
  - Existing Flight Data
  - No Data
- Reviewing Candidate Parts for a Flight Project
  - What information should be provided to the radiation engineer
  - What should the radiation engineer provide to the project
- Radiation perspective on device selection
  - Finding data
  - Interpreting data
    - Wafer or lot qualification
    - Application
    - Data completeness
  - Determining test requirements versus risk

The Trade Space Involved With Part Selection

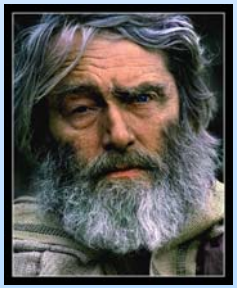
- With the advent of modern complex microelectronics in space systems, the selection methods used in earlier space systems has changed
  - OLD: Buy Radiation Hardened Devices Only
  - NEW: Develop Radiation Tolerant Systems
- Systems design is more complex than a simple part purchase. It involves a risk management approach that is often quite difficult.
- The risk management may be broken into three considerations
  - Technical/Design – "The Good"
  - Programmatic – "The Bad"
  - Radiation/Reliability – "The Ugly"
- Understanding Risk and the Trade Space involved is the new key to mission success

Understanding Risk

- **Technical risks**
  - **Relate to the circuit designs not being able to meet mission criteria such as jitter related to a long dwell time of a telescope on an object**

- **Programmatic risks**
  - **Relate to a mission missing a launch window or exceeding a budgetary cost cap which can lead to mission cancellation**

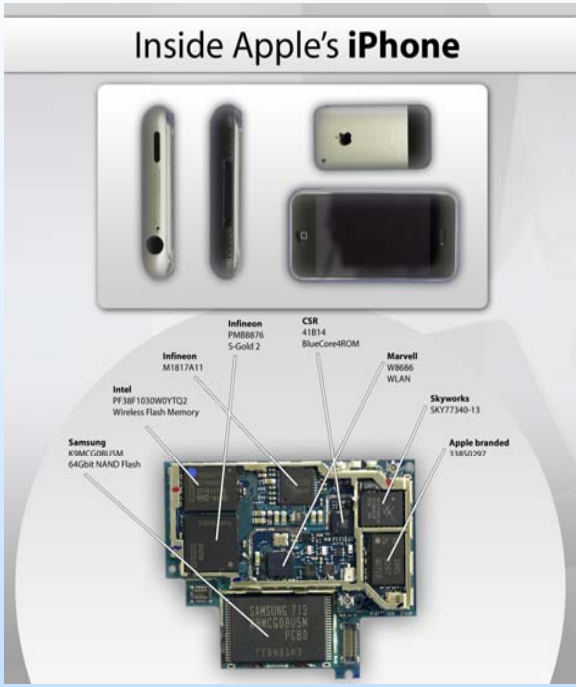
- **Reliability risks**
  - **Relate to mission meeting its lifetime and performance goals without premature failures or unexpected anomalies**



- ***Each mission must determine its priorities among the three risk types***

Technical/Design Aspects

- **Rationale**
  - **Trying to meet science, surveillance, or other performance requirements**
- **Personnel involved**
  - **Electrical designer, systems engineer, other engineers**
- **Usual method of requirements**
  - **Flowdown from science or similar requirements to implementation**
    - **I.e., ADC resolution or speed, data storage size, etc…**
- **Buzzwords**
  - **MIPS/watt, Gbytes/cm^3, resolution, MHz/GHz, reprogrammable**
- **Limiting technical factors beyond electrical**
  - **Size, weight, and power (SWaP)**

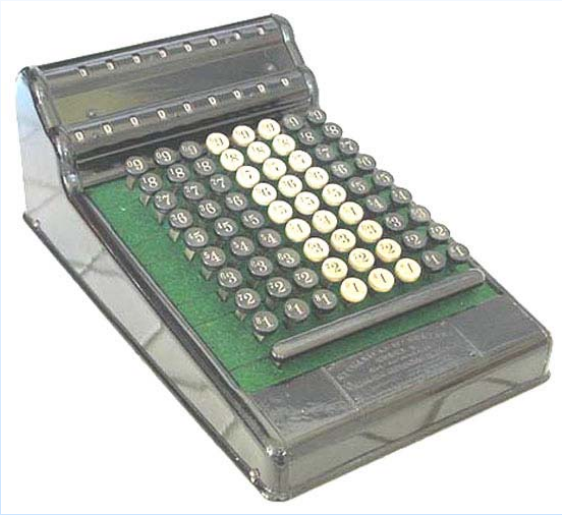


Performance

Inside a Apple iPhone™ player

Programmatic Overview

- **Rationale**
  - **Trying to keep a program on schedule and within budget**
- **Personnel involved**
  - **Project manager, resource analyst, system scheduler**
- **Usual method of requirements**
  - **Flowdown from parent organization or mission goals for budget/schedule**
    - **I.e., Launch date**
- **Buzzwords**
  - **Cost cap, GANTT/PERT chart, risk matrix, contingency**
- **Limiting factors**
  - **Parent organization makes final decision**

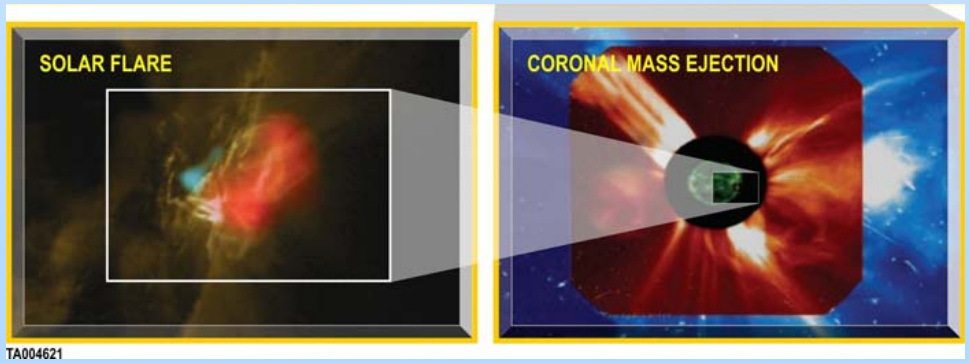


Programmatics

A numbers game

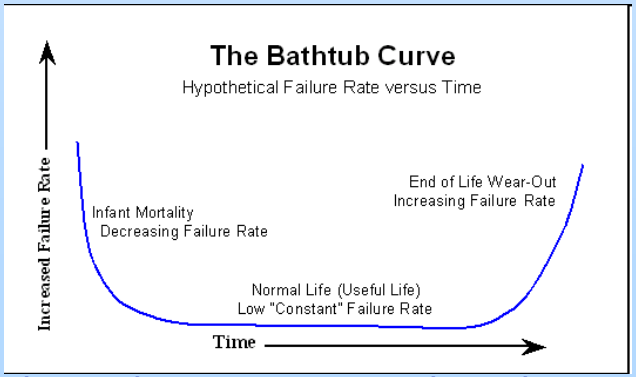
Radiation Perspective

- **Rationale**
  - **Trying to ensure mission parameters such as reliability, availability, operate-through, and lifetime are met in the space radiation environment**
- **Personnel involved**
  - **Radiation engineer**
- **Usual method of requirements**
  - **Flowdown from mission requirements for parameter space**
    - **I.e., Availability requirement may drive SEU rate requirements**
- **Buzzwords**
  - **Total dose, Single events, Mitigation**
- **Limiting factors**
  - **Management normally makes "acceptable" risk decision**
- **Example trade: buy radiation hardened versus test commercial devices**



Reliability Considerations

- **Rationale**
  - **Trying to ensure mission parameters such as reliability, availability, operate-through, and lifetime are met**
- **Personnel involved**
  - **Reliability engineer, parts engineer**
- **Usual method of requirements**
  - **Flowdown from mission requirements for parameter space**
    - **I.e., Mission lifetime**
- **Buzzwords**
  - **Lifetime, device screening, "waivers"**
- **Limiting factors**
  - **Management normally makes "acceptable" risk decision**



An Example "Ad hoc" Battle

- **Mission requirement: High resolution image**
  - **Flowdown requirement: 14-bit 100 Msps ADC**
    - **Usually more detailed requirements are used such as ENOB or INL or DNL as well**
  - **Designer**
    - **Searches for available radiation hardened ADCs that meet the requirement**
    - **Searches for commercial alternatives that could be upscreened**
  - **Manager**
    - **Trades the cost of buying Mil-Aero part requiring less aftermarket testing than a purely commercial IC**
    - **Worries over delivery and test schedule of the candidate devices**
  - **Radiation/Parts Engineer**
    - **Evaluates existing device data to determine reliability performance and additional test cost and schedule**
- **The best device? Depends on mission priorities**

Remember:

A Single Device May Drive Other Electronics Requirements

Increasing System Complexity

One-time Programmable (OTP)

- FPGA

Non-volatile Reprogrammable (Flash)

- Circuits to interface between FPGA and ground for new configuration uploads
- FPGA

SRAM-based

- Circuits to interface between FPGA and ground for new configuration uploads
- Watchdog/ controller
- FPGA
- Non-volatile memory (NVM) – holds configuration of FPGA

Sample System Implementation for the Three Styles of FPGAs

Reviewing a Parts List –
Information Provided to the Radiation Engineer

- **The following is a list of information that should be provided to the radiation engineer to perform a review or "scrub" for radiation issues from a designer's desired ICs**
  - **Manufacturer (not the vendor, but who built the part/die)**
  - **Part number (generic)**
  - **Standard military or aerospace procurement number possibly including radiation hardened designators**
  - **Function**
  - **Lot date code (LDCs)**
    - **This can be tricky: the package and the die can have two separate LDCs**
    - **Hybrid devices pose a challenge for identifying internal LDCs**
    - **In some cases, the design is still in preliminary stages and the question involves a survey of a device and it's radiation tolerance**
      - **If data exists on a device, it can be used as a initial point for device selection or rejection**
      - **Ex., Vendor X SDRAM has data showing reasonable tolerance based on testing for project A**
        - » ***Project B may use this criteria to select this part, however, lot qualification and application interpretation are required or risk is being assumed***

Reviewing a Parts List –
Additional Information Needed for Parts List Review

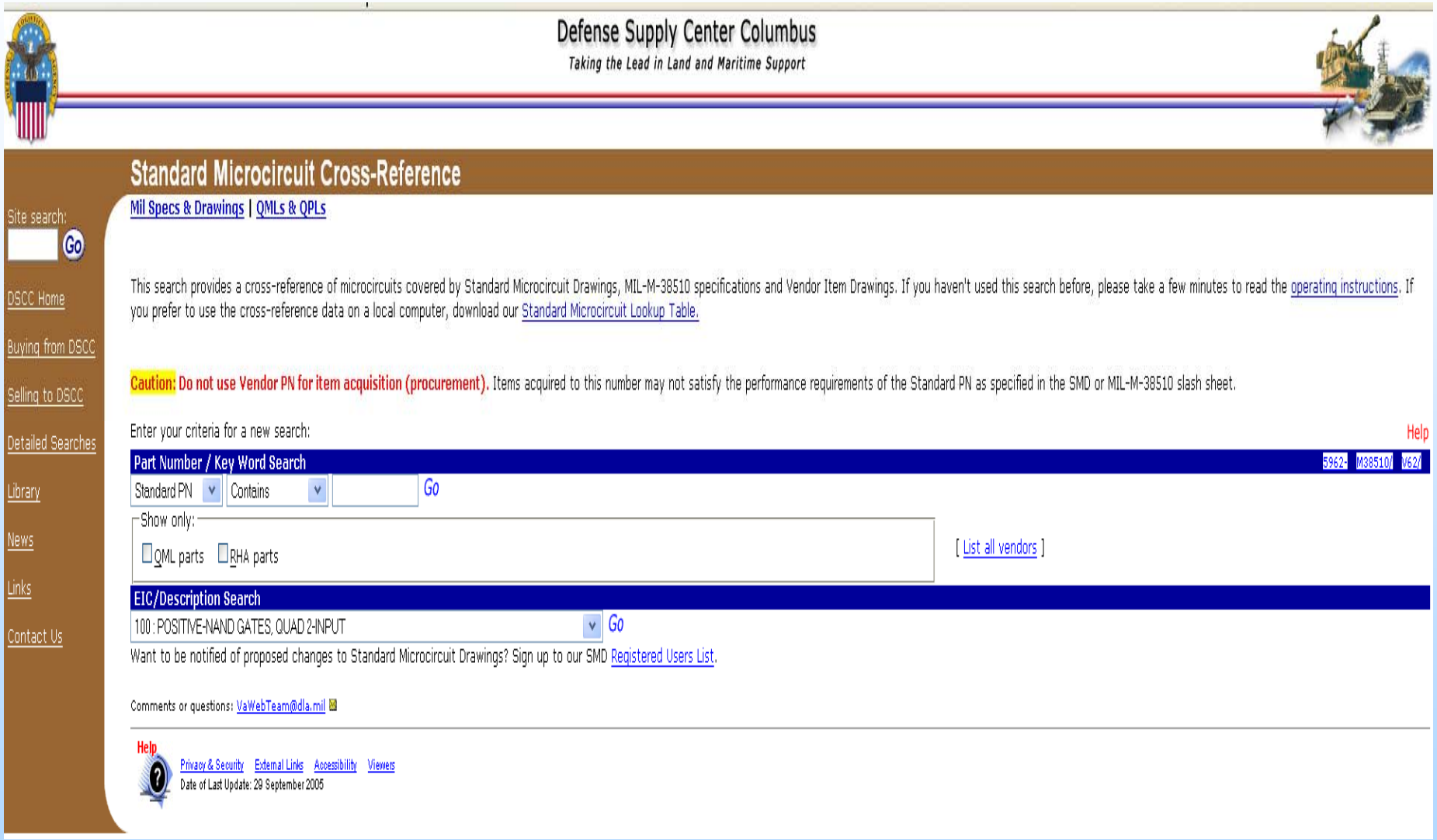
- **Technology of the part**
  - **Determines appropriate test methods for device qualification**
  - **This information may not be readily available and interaction with the manufacturer may be required**
  - **Example**
    - **Linear Bipolar Device**
      - **Was TID testing performed at low dose rate (as per standards) or is the device "ELDRS-free"?**
- **Specific device application information such as**
  - **Operating speed, differential voltages, utilization rates, and so forth**
- ***Note: Parts List Reviews may divided into two steps***
  - **1st step simply determines available data as a "pre-selection" criteria**
  - **2nd pass applies existing information and data to specific application and mission**

Diatribe: U.S. Procurement Specification

- Military and procurement specifications are often found on parts lists. These may be in the form of
  - SMD
    - Standard Microcircuit Drawing
      - There may also be Mil-38510 or vendor drawings
  - QPL
    - Qualified Parts List
  - QML
    - Qualified Manufacturers List
  - RHA
    - Radiation Hardness Assurance (RHA)
      - This refers to the RHA designator for total ionizing dose (TID) only. Single event effects (SEE) are NOT guaranteed by the RHA designator as a rule.
- DSCC
  - Defense Supply Center Columbus
    - http://www.dscc.dla.mil/
  - DSCC website and downloadable tools are useful in translating generic part numbers (p/n) to/from 5962 (Mil p/n)
- ESA also has a system of standardizing parts procurement

DSCC Website

- **http://www.dscc.dla.mil/Programs/Smcr/**



Feedback to the Flight Project

- If the part is guaranteed for radiation
  - Does the guaranteed radiation tolerance meet all mission requirements?
    - Not all guaranteed parts will meet a mission requirement or APPLICATION
- If the part has ground test data available
  - Synopsis of the tolerance levels noted
    - Note: many database radiation results are application-specific
      - Results showing good tolerance may be used as an indicator the part might be acceptable for selection, however, further testing may be required
  - LDCs of the tested parts
    - Comparing the LDC (lot and wafer) of tested part versus currently available LDCs may be difficult
      - Unless it's a known lot that's being purchased, radiation qualification testing is often required
  - Testing recommendations based on requirements and part technology
  - Alternate device recommendations
- If the part does not have data
  - Is there data on the process?
  - Is there data on a similar or more complex part on the same process?
    - This is a judgment call as to defining risk: if there is consistent existing data on other devices on the process, it should be noted
- Previous Flight Usage (discussed later)
- SEE rate predictions for the mission may be included

Radiation and Process Consistency

- The technology a device is built with (CMOS, Bipolar, etc…) as well as process particulars (material thicknesses, feature size,…) and electrical characteristics (Vdd, fmax, etc…) are all inter-related for radiation response
- In general, Mil/Aero manufacturers work to control process changes that might impact radiation characteristics while COTS vendors focus solely on improving yield (successful die per wafer)
  - There are examples from both sides where small process changes have impact to radiation tolerance
    - Ex., NSC and TID hardness of the LM series
      - Moved fab site to "identical" fab and no longer had a 100krad part!
      - They worked VERY hard to get back to 100 krads
    - Analog Devices XFCB process has shown consistent TID performance although many are not RH products
  - The process information is required to determine if the proper physics were used in the testing of the device
    - Examples include low dose rate effects and angular SEE issues
- COTS parts may have a wide variability and lot specific data is HIGHLY recommended

Why Lot Qualification - Examples

- **Devices from three different 80486DX2-66 lots were tested, with varying SEE characteristics. In particular, microlatchup LET_{th} varied between LETs of 20 and 37.2.**
  - **Slight variation in the manufacturing process may lead to significantly different single event effect sensitivity, especially without the strict process control of military-process parts.**
- **Because of this type of variability in commercial devices, lot screening is recommended strongly.**

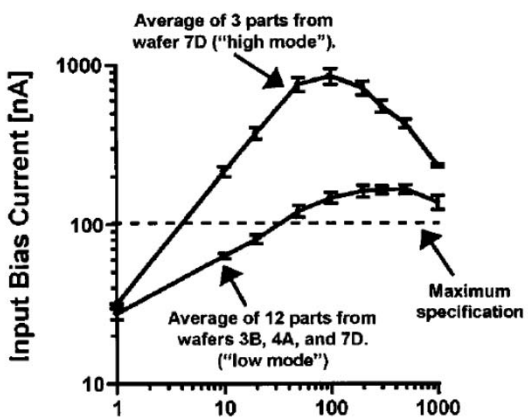


Fig. 1. Comparison of high and low mode LM111 circuits responses for room temperature 50 rad(SiO_2)/s irradiations. The results indicate a broad distribution in circuit response.

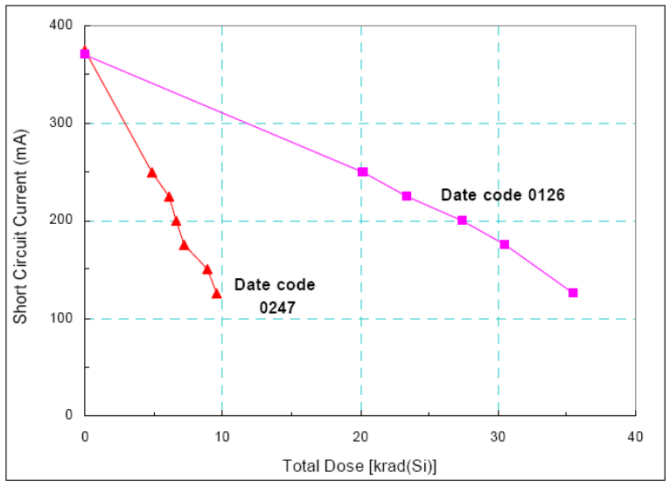
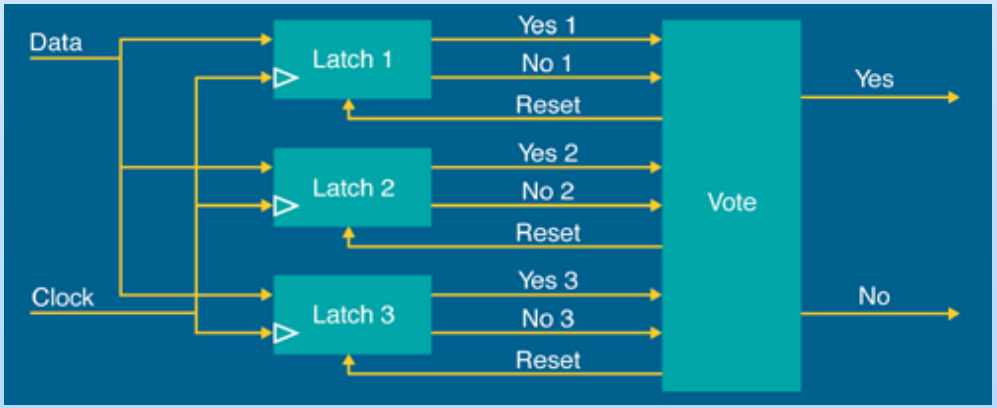


Fig. 2. Short circuit current as a function of total dose at a dose rate of 0.005 rad(Si)/s. Parts are from the same manufacturer represented in Figure 1.

Radiation Perspective on IC Selection

- **From the radiation perspective, ICs can be viewed as one of four categories.**
  - **Guaranteed hardness**
    - **Radiation-hardened by process (RHBP)**
    - **Radiation-hardened by design (RHBD)**
  - **Historical ground-based radiation data**
    - **Lot acceptance criteria**
  - **Historical flight usage**
    - **Statistical significance**
  - **Unknown assurance**
    - **New device or one with no data or guarantee**



RHBD Voting Approach

http://www.aero.org/publications/crosslink/summer2003/06.html

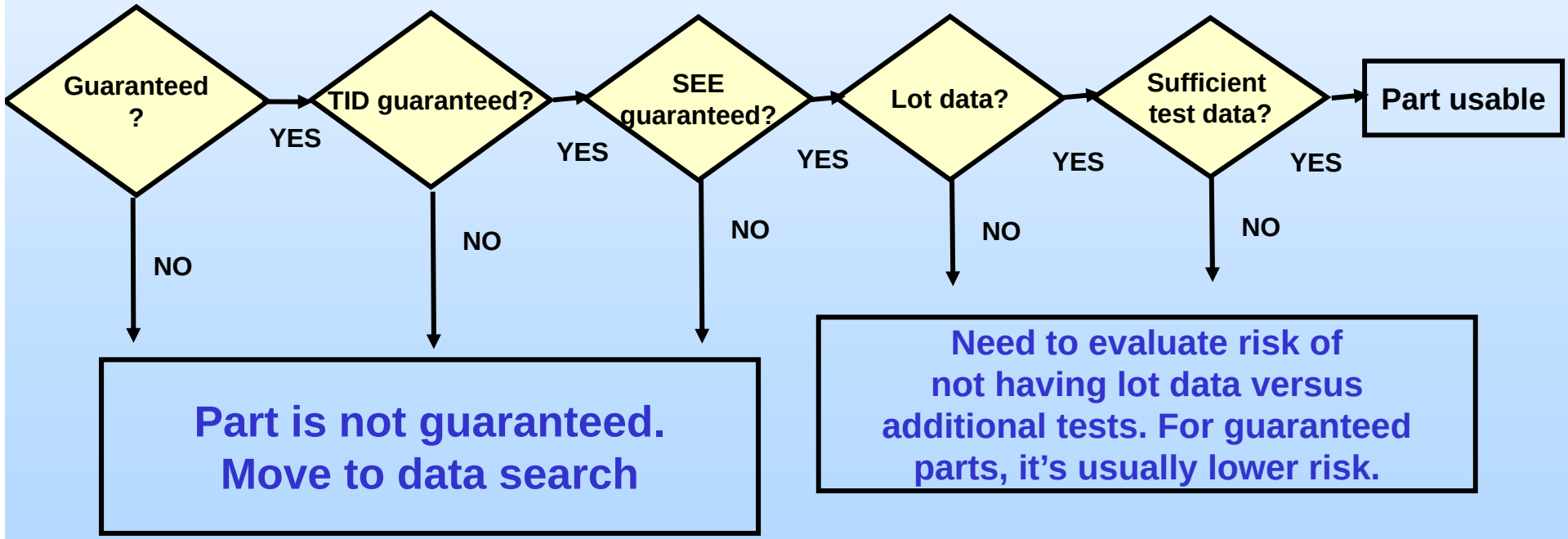
Guaranteed Radiation Tolerance

- So, we've started perusing the review of parts guaranteed by the vendor or using a procurement standard specification (ESA or through DSCC)
  - Now let's move on to a bit more detail
- A limited number of semiconductor manufacturers, either with fabs or fabless, will guarantee radiation performance of devices
  - Examples:
    - ATMEL, Honeywell, BAE Systems, Aeroflex
  - Radiation qualification usually is performed on either
    - Qualification test vehicle,
    - Device type or family member, or
    - Lot qualification
  - Some vendors sell "guaranteed" radiation tolerant devices by using specific lots of commercial devices (with test data) coupled with mitigation approaches external to the die
- The devices themselves can be hardened via
  - Process or material (RHBP or RHBM),
  - Design (RHBD), or
  - Serendipity (RHBS)

Most radiation tolerant foundries use a mix of hardening approaches

Evaluating "guaranteed" parts

- **Even guaranteed parts may have issues**
  - **Guarantees for TID and SEE**
  - **Lot testing requirements**
  - **Application-specific issue (how was the qualification done???)**



Example: ACTEL RH1280 FPGA

- **Total dose is guaranteed to 300 krads (Si)**
- **SEL is guaranteed to be SEL-free**
- **SEU is a marketing number determined by the vendor**
  - ***Results may not be applicable to YOUR mission or application.***

Radiation Specifications[1, 2]

Symbol	Characteristics	Conditions	Min.	Max.	Units
RTD	Total Dose			300K	Rad(Si)
SEL	Single Event Latch-Up	$-55°C \le T_{case} \le 125°C$		0	Fails/Device-Day
SEU1[3]	Single Event Upset for S-modules	$-55°C \le T_{case} \le 125°C$		1E-6	Upsets/Bit-Day
SEU2[3]	Single Event Upset for C-modules	$-55°C \le T_{case} \le 125°C$		1E-7	Upsets/Bit-Day
SEU3[3]	Single Event Fuse Rupture	$-55°C \le T_{case} \le 125°C$		<1	FIT (Fails/Device/1E9 Hrs)
RNF	Neutron Fluence		>1E+12		N/cm^2

Notes:

1. *Measured at room temperature unless otherwise stated.*
2. *Device electrical characteristics are guaranteed for post-irradiation levels at 25°C.*
3. *10% worst-case particle environment, geosynchronous orbit, 0.025" of aluminum shielding. Specification set using the CREME code upset rate calculation method with a 2μ epi thickness.*

Example: Honeywell HX6228 SRAM

- **Total dose is guaranteed to 1 Mrads (Si)**
- **SEL is guaranteed to be SEL-free**
- **SEU is guaranteed to show low susceptibility. However, in more complex devices speed and geometric issues may not have been looked at**

RADIATION

- Fabricated with SOI-IV CMOS 0.7 µm (L_{eff} = 0.55 µm)
- Total Dose Hardness through $1x10^6$ rad(Si)
- Neutron Hardness through $1x10^{14}$ N/cm^2
- Dynamic and Static Transient Upset Hardness through $1x10^{11}$ rad(SiO_2)/s
- Dose Rate Survivability through $1x10^{12}$ rad(SiO_2)/s
- Soft Error Rate of $<1x10^{-10}$ upsets/bit-day in Geosynchronous Orbit
- No Latchup

Xilinx Radiation Tolerance?

Guaranteed Radiation Tolerance

Virtex-4QV FPGAs are guaranteed for total ionizing dose (TID) and single-event latch-up (SEL) immunity. Xilinx pioneered the application of SRAM-based FPGAs in high-radiation environments and together with JPL founded the SEE Consortium to conduct single-event upset (SEU) characterization and report the results. To obtain Consortium reports, visit: *http://parts.jpl.nasa.gov/resources.htm.*

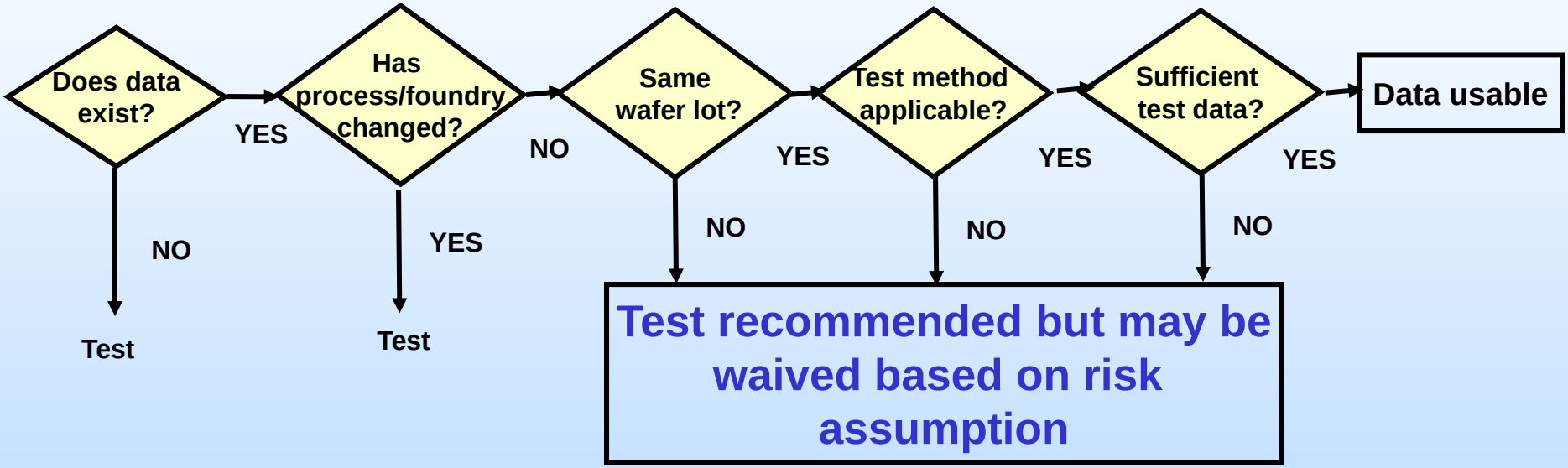
- **Total Ionizing Dose**–Xilinx tests each wafer lot per Method 1019 to ensure that device performance meets or exceeds the guaranteed DC electrical specification requirements, as well as AC and timing parameters at 300 krad (Si).
- **Single-Event Latchup**–The radiation-tolerant Virtex-4QV technology incorporates a thin epitaxial layer in the wafer manufacturing process for latch-up immunity. For each Virtex-4QV device type, the SEE consortium verifies latchup immunity at maximum VCC and operating temperature, subjected to a heavy ion fluence exceeding $1 \cdot 10^7$ particles/cm2, with linear energy transfer (LET) exceeding 125 $MeV \cdot cm^2/mg$.
- **Single-Event Upset**–Xilinx conducts additional experiments in heavy ion, proton, and neutron environments in order to measure and document the susceptibility and consequence of SEU(s). The SEE Consortium oversees and validates the test methods, empirical data collected, and resulting analysis.

In conjunction with the SEE Consortium, Xilinx develops beam-tested, upset mitigation solutions. For mitigation, Xilinx provides triple modular redundant reference designs, configuration memory scrubbing application notes, and the TMRtool™ for automating error-free triplication of designs destined for space.

Very application specific

Archival Radiation Performance – Ground-based Data

- **In general, the flow is shown below**



Sources of Radiation Data

- **Manufacturers (datasheets as well as databases)**
- **IEEE (Transactions and Radiation Effects Data Workshop), RADECS and other Proceedings**
- **Websites**
  - **http://nepp.nasa.gov**
  - **http://radhome.gsfc.nasa.gov**
  - **http://radcentral.jpl.nasa.gov/**
    - **US citizen only**
  - **https://escies.org/ReadArticle?docId=747**
    - **ESA database**
  - **http://erric.dasiac.com/**
    - **Currently off-line**
  - **There are others that are extinct (REDEX), and some that charge for usage (SEUDATA), but**
- ***Search engines such as Google are a good start as well***

Sample Google Search

Web Images Maps News Shopping Gmail more ▾

Google ad590 radiation Search Advanced Search Preferences

Web

OWL2 to LM34 & **AD590** temperature sensors
The **AD590** is available with the military designation is 5962-87571, available in class V qualified for space applications, RHA (**Radiation** Hardness ...
www.emesystems.com/OL2heat.htm - 23k - Cached - Similar pages

Test results of total ionizing dose conducted at the jet ...
E.**AD590**. The **AD590** devices irradiated with an applied bias voltage. of 5 volts and 15 volts were far less affected by **radiation** ...
ieeexplore.ieee.org/iel5/9357/29718/01352901.pdf?arnumber=1352901 - Similar pages

Welcome to IEEE Xplore 2.0: Mechanisms of Enhanced **Radiation** ...
... "Total dose and dose rate response of an **AD590** temperature transducer," Proc. **Radiation** Effects Components and Systems Workshop Athens, Greece, 2006. ...
ieeexplore.ieee.org/xpls/abs_all.jsp?isnumber=4394990&arnumber=4395094&count=114&index=12 - Similar pages
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[PDF] STANDARD MICROCIRCUIT DRAWING MICROCIRCUIT, LINEAR, **RADIATION** ...
File Format: PDF/Adobe Acrobat - View as HTML
When available, a choice of **Radiation** Hardness Assurance (RHA) levels are .... **Radiation** end point limits for the noted parameters are guaranteed only for ...
www.dscc.dla.mil/downloads/MilSpec/Smd/87571.pdf - Similar pages

Space vehicle with temperature sensitive oscillator and associated ...
However, RTDs require complex conditioning of the low signal level, and the **AD590** may require special shielding in space due to **radiation** susceptibility. ...
www.patentstorm.us/patents/6390672-description.html - 34k - Cached - Similar pages

[PDF] **Radiation** Effects Data Workshop Index 2004
File Format: PDF/Adobe Acrobat
AD590. Temperature Sensor. Analog Devices ... the response data required has been located it is the **radiation** effects engineer's responsibility to perform a ...
www.nsrec.com/redw/2004.pdf - Similar pages

ScienceDirect - **Radiation** Physics and Chemistry : Advanced ...
Experiments were conducted using a **radiation** dynamics electron beam accelerator ... WCOTT, Wire Current Output temperature transducer—Intensil, GE-**AD590**, ...
linkinghub.elsevier.com/retrieve/pii/S0969806X01005606 - Similar pages

cmspaper.word
It is used to check the **radiation** hardness of the pre-production crystals. .... The temperature sensors are **AD 590** protected from the **radiation** behind the ...
wwwlapp.in2p3.fr/cms/GIFUSERMANUAL-X5.html - 64k - Cached - Similar pages

Cosmic Ray Telescope for the Effects of **Radiation**
Cosmic Ray Telescope for the Effects of **Radiation** ..... **AD590** Temperature Transducer Analog Devices AD590LF/883B 32-10201.7002 6 . ...
snebulos.mit.edu/dbout/32-data.html - 185k - Cached - Similar pages

Done

Test Data:
Is the data applicable?

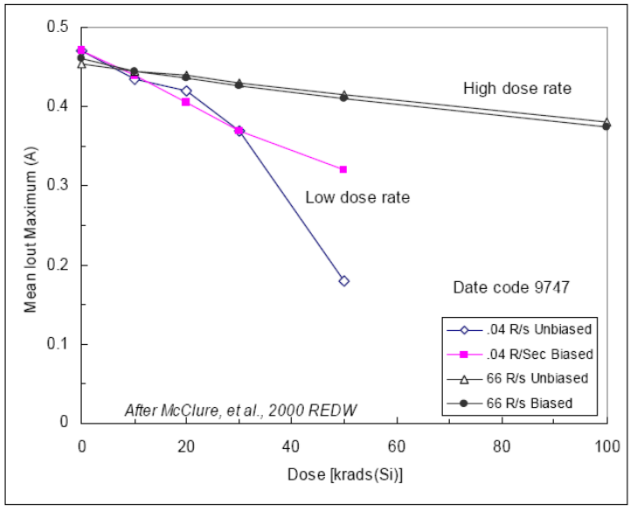
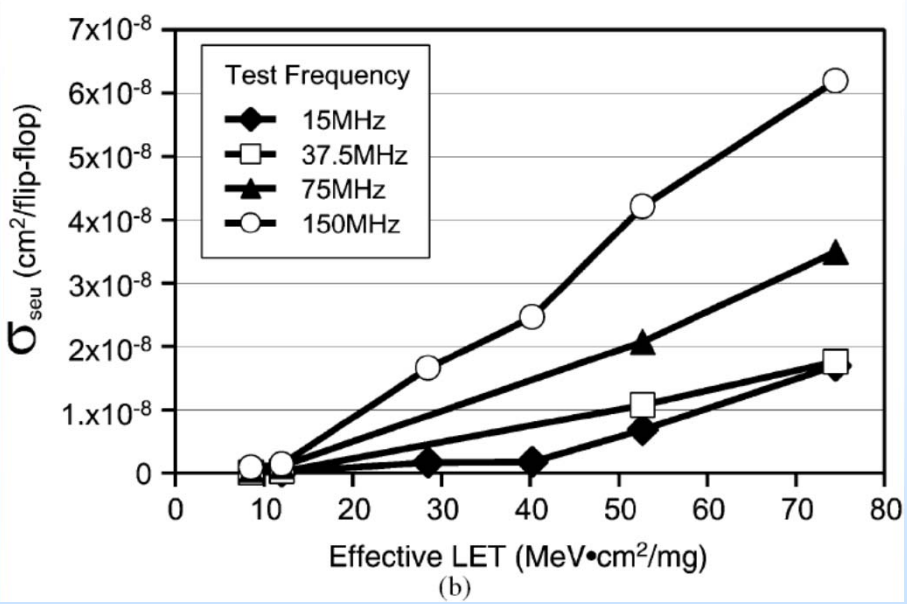


Fig. 1. Test results for an earlier lot of LP2953 low dropout regulators [3].

ELDRS



Operating Frequency Effects

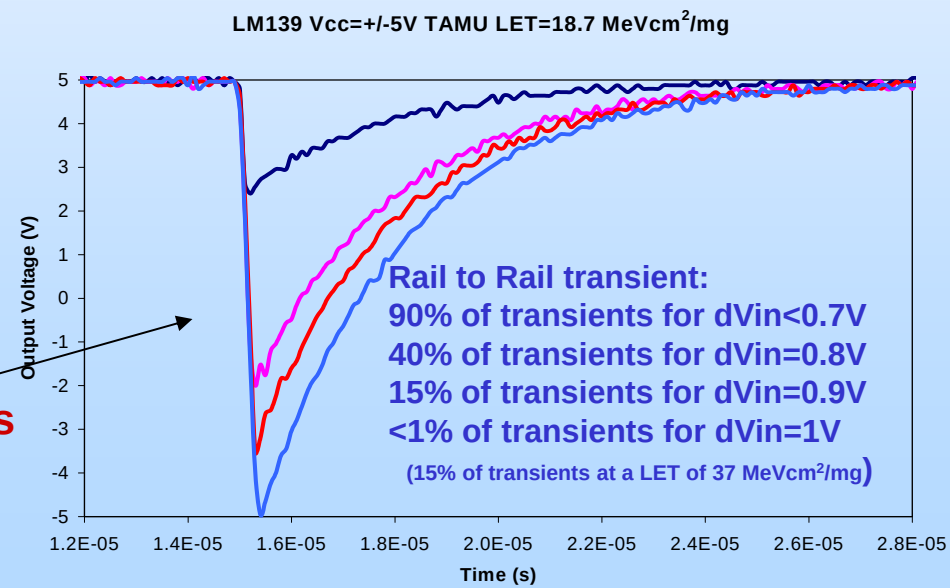
Other items include:

Angular responses, application-specific results, temperature effects, …

Data Applicability – Example 1

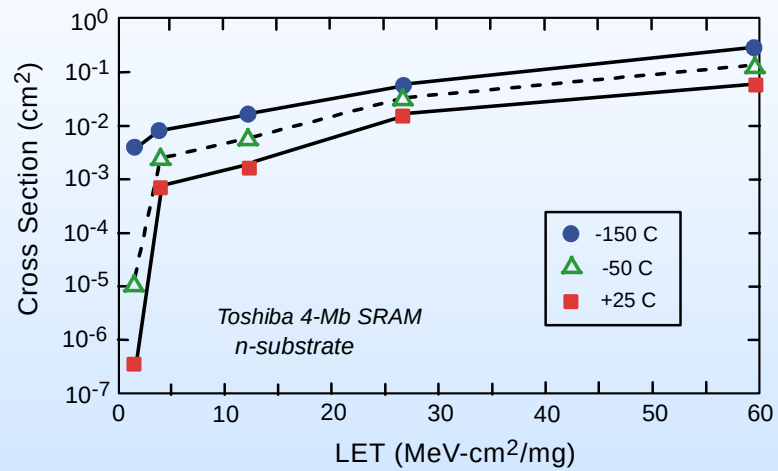
- **Most SEE data available is application-specific**
  - **Power supply voltages**
  - **Operating frequency**
    - **Fidelity of response measured**
      - **Ex., Was the scope fast enough to capture "small" transients that might perturb sensitive data?**
  - **Circuit load**
  - **Test patterns**
  - **Temperature**
  - **Bias configuration**

Transients in a linear device can vary with input parameters



Data Applicability - Example 2

- **SRAM used in a solid state recorder (SSR)**
  - **SEE ground test data may have been in dynamic mode with a 1 MHz operating frequency**
  - **Application may be quasi-static**
    - **Write once an orbit (collect data)**
    - **Read once an orbit (downlink data)**
  - **There is often a duty cycle effect for SEE sensitivity**
    - **Device may be more or less sensitive in a quasi-static mode of operation**
  - **Device may also have a prevalence of 0-1 vs. 1-0 upset**
    - **Implies SEU sensitivity is a function of data patterns**
      - **If test pattern is all 1's or all 0s, data may not be applicable**
        - » **Hitachi 1 Mbit SRAM was 49X more sensitive in one direction than the other!**



Effect of temperature on SEE sensitivity

Applying the Data: Is a Failure Always a Failure?

- **Beyond just the data that exists on a device, applying that data to an application must be considered**
- **Two examples**
  - **Memory A has a very low LET_{th} for single bit errors**
    - **Bits are interleaved so that each error only affects 1 bit in a logical word**
    - **System is running a Hamming Code EDAC over top**
      - **SECDED: single error correct, double error detect**
    - **As long as the probability for two independent events (i.e., upsets) is very small between EDAC scrubs, device is usable**
  - **Linear device B shows degradation of parameter Z exceeding the spec at 10 krads-Si**
    - **Circuit design analysis shows that Z can increase to 10Z before circuit stops functioning**
    - **Waiver of this device for this parameter may be acceptable (assuming of course, mission requirements and actual 10Z or other parameters failure levels)**

Archival Radiation Performance – Flight Heritage

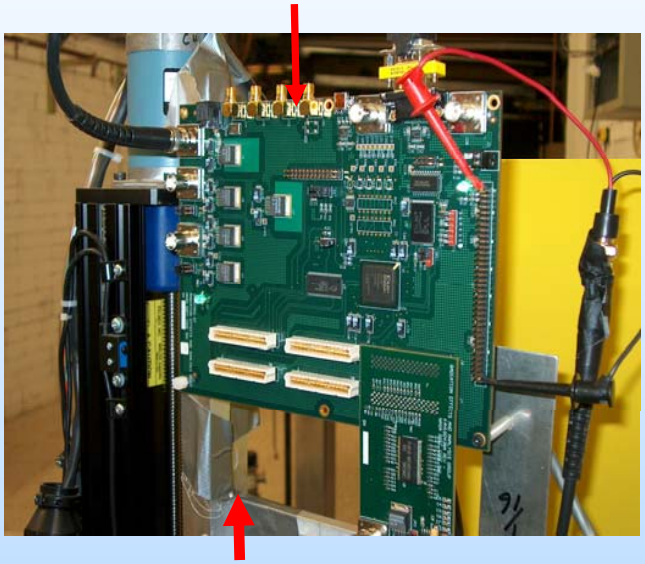
- Can we make use of parts with flight heritage and no ground data for new mission?
- Similar flow to using archival ground data exist, but consider as well
  - Statistical significance of the flight data
    - Environment severity?
    - Number of samples?
    - Length of mission?
    - Ex. 1 part flying for 3 years in a LEO orbit doesn't mean much to a 10 year mission to Mars!
  - Has storage of devices affected radiation tolerance or reliability?
  - And so forth
- This approach is rarely recommended by the radiation expert

Some heritage designs last better than others

IC's with no Guarantee or Heritage

- **Testing is usually required**
  - **The true challenge is to gather sufficient data in a cost and schedule effective manner.**
    - **A backup plan should be made in case device fails to pass radiation criteria.**
- **The hard question is when do we need to test.**
  - **One must consider**
    - **Mission parameters**
    - **Application/operation**
    - **Process and device family knowledge**
  - **In some cases, we can make an educated guess for "worst-case" such as SET size**

FPGA-based motherboard

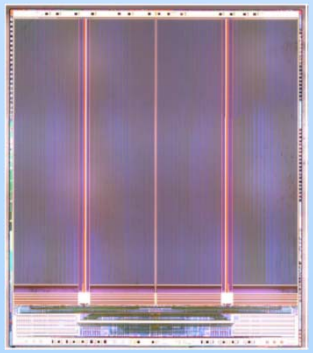


SDRAM mounted on a daughtercard

"Abandon all hope, ye' who enter here"

Is Testing Always Required?

- **Exceptions for testing may include**
  - **Operational**
    - **Ex., The device is only powered on once per orbit and the sensitive time window for a single event effect is minimal**
  - **Acceptable data loss**
    - **Ex., System level error rate may be set such that data is gathered 95% of the time. This is data availability. Given physical device volume and assuming every ion causes an upset, this worst-case rate may be tractable.**
  - **Negligible effect**
    - **Ex., A 2 week mission on a shuttle may have a very low TID requirement. TID testing could be waived.**



A FLASH memory may be acceptable without testing if a low TID requirement exists or not powered on for the large majority of time.

Qualification by Similarity

- Using generic or family data (e.g., family qualification, library qualification)
- After considering not only lot-to-lot and application-specific issues, qualification by similarity must determine if Part A's internal circuitry is well covered by Part B's data.
  - I.e., How good does a shift register or ring oscillator do in predicting CPU radiation performance?
- Qualification by similarity has increasing risk with device complexity, but for simpler devices may be sufficient in risk reduction
  - Ex., a quad flip-flop having data being used for a dual flip-flop of same design and process
    - Good luck determining "SAME"

It's All About Risk

- **Rule #1: There will always be risks associated with any use of electronics in a space radiation environment**
  - **A radiation engineer's job is to minimize and to determine what is reasonable risk**
- **Lot and application-specific information and guaranteed devices ARE the best choices**
  - **Risk is being assumed at all other times**
  - **Historical performance can be an indicator for usage, but may have high risks**
    - **How much risk is a judgment call based on available information**
      - **It is the radiation engineer's job to find the information and make recommendations**