Aerospace Constituency Group Brief In

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Outline

- Where This Group Fits into the Generic Charge
- Discussion of Challenge Problems
- Possibly Interesting Solutions/Discussion Points

Aerospace Organizations and Culture

- **Predominantly, this field consists of consumers and not manufacturers of electronic components**
  - Despite large, date-lot buys most aerospace organizations do not have enough weight to sway the market – most manufacturers are interested in designing parts for the cell phone market
  - Dependent on aerospace, trusted-foundry manufacturers (BAE, Honeywell, Harris, Aeroflex, and some IBM)
  - Increasing forays into using commercial manufacturers, although new technology insertion from these manufacturers is not simple
- **Most organizations will design and/or fabricate payloads in house**
- **While normally a conservative field, due to recent events, the field is currently even more conservative**
  - Sponsors are looking for ways to guarantee satellites work flawlessly
  - Technology is trending to less reliable hardware, no repair options
  - Less reliable parts and conservativeness is leading to even larger design margins
  - Efforts to help payload/satellite designers manage the complexity of security and reliability problems will make a big difference for this field

Mission Requirements

- **Most aerospace organizations are contracting to "hosting" organizations to provide anything from single boards to instruments to satellites or rely on hosts to provide launches**
  - Host organizations holds accountability for satellite/launch failures
  - Host organizations often not openly discussed
- **Host organization specifies both the mission and the hard limits on performance, power, reliability, weight, and thermal**
  - Reliability, power, weight, and performance are currency in this culture
  - A definite tradespace between information and energy exists already, although currently manually addressed
- **There are often problems that are caused by the separation between the hosts and designers**
  - Reliability requirements might be written in a way that demands more mitigation and more validation, which can drive up weight, power, and costs
  - Reliability requirements might written in a way that demands unattainable validation requirements
  - Hosts have increasing mission needs

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Aerospace Systems as Life-Critical Systems

- **Avionics are clearly life-critical systems**
  - There are FAA standards for both the reliability of software and hardware systems
- **NASA's manned missions are clearly life-critical systems**
- **The national asset satellite system are <u>also</u> a life-critical systems**
  - Data taken off of these satellites are used to make policy decisions that can affect
    - Warfighters in the theatre
    - Political environments between countries
  - Recently the FAA standards have been creeping toward these satellites

Aerospace as a Testing Culture

- **Because of the harsh radiation environment, devices are independently tested in accelerated radiation environments**
  - Space radiation researchers publish data in the IEEE Transactions on Nuclear Science and the Radiation Data Workshops associated with both the Nuclear and Space Radiation Effects Conference (NSREC) and the Radiation and Its Effects on Components and Systems (RADECS) Conference
  - Less true for avionics than space
  - Commercial manufacturers less open with radiation test data
- **While testing is costly in both time and expense, right now it is the only accepted method of determining whether parts are acceptable for space usage**
  - Some success modeling analog devices, but there are still enough “gotchas” to keep people from relying on modeling solely
  - Fault injection becoming increasingly more available and relied upon for doing the initial analysis for dynamic behavior of advanced processing elements, minimizing but not eliminating the need for radiation testing

Upset Rate A (Unpredictability, Wearout, Etc.)

- **For each component in a system, the designer needs to understand all of the reliability problems that come from:**
  - Total ionizing dose (TID): constant exposure to radiation causes accelerated wearout of device
  - Single event effects (SEE): an umbrella term that covers ten different reliability problems by single ions interacting with the device; could cause devices to change intermediate processing values or device failure
  - Weapons effects: exposure to manmade radiation could cause device failure
  - Thermal: constant and extreme temperature cycling or power cycling the device causes accelerated wearout of the device
- **Reducing the problem to "only single event upsets" is an inaccurate assessment of the problem**
  - Most devices suffer from multiple reliability problems that cause an array of data corruption, device availability, device failure, and wearout issues
- **These problems are not unique to our devices – its only that the probability of occurrence at sea level is very low**

Significant Radiation Reliability Issues with Most Electronics

- **Memory**
  - Continued significant increase in fraction of multiple bit upset (MBUs) from a single ionizing particle as feature size decreases, which could be solved with different EDAC, except…
  - Device availability issues from latchup and single-event functional interrupts (SEFIs) and wearout issues from TID outstrip many SEU/MBU problems
- **Analog**
  - The choice is often high-speed, commercial parts with radiation problems or slower rad-hard parts
  - Latchup issues are dominating device issues
  - Single event transients (SETs) with duration of up to ~20 µsec make it difficult to distinguish between data and noise
- **Processing Elements – FPGAs, DSP, Microprocessors, Multi-core**
  - Deficiency of High speed, HiRel I/O which is leading to a deficiency of High speed, HiRel Processing elements
  - Single-event functional interrupts cause device availability issues
  - Complexity of how induced error is propagated through system
  - Best solutions are commercial and testing, analog, and memory gap worsen

Upset Rate A Issues Can Interlock with Other Problems

- **Performance, power, and temperature can affect "Upset Rate A" issues**
  - Increasing performance, increases temperature, which increases wearout and SEE issues
  - Decreasing power, increases SEE issues
- **On larger satellites, each dimension of the problem could have entire teams of engineers focusing on that aspect of the problem, as well as a mechanical team**
- **Each decision can easily turn into a cascading set of problems, where each problem is translated into a different type of problem**
  - For example: a performance problem is solved by using a more advanced processing element, which causes a…
  - Reliability problem that is solved by using TMR, which causes a…
  - Thermal problem that is solved by using heat pipes, which causes a…
  - Mechanical problem that has be extensively tested and reviewed by several organizations before launch to determine whether the new processing element will be ripped off the payload at launch by the heat pipes

FIT Rate B, C, and D?

- **We do not use "FIT" as a term, we use bit cross-sections for SEU, device cross-sections for SEL, TID values, etc…**
  - These values are used with orbital modeling tools to turn these values into bit-upset/day, device-upset/day, dose/year

- **Unlike other consumers, we start with good knowledge of how the system should work in our radiation environment**
- **Unlike other consumers, we have fewer tools to help designers manage the complexity of (performance, reliability, power, thermal) problems to allow the designers to focus on design**
- **Unlike other consumers, we build one at a time often taking 5-10 years at a time**

Overview of Challenge Problems

- **Fixed mission/science capability**
- **Complex, multidimensional problem with fixed hard limits on (power, thermal, reliability) mission requirements**
- **Widening gap between mil/aero and commercial parts**
- **Design for worst case environment**
- **Testing bottleneck**
- **System reliability has not been simplified into a tractable problem**

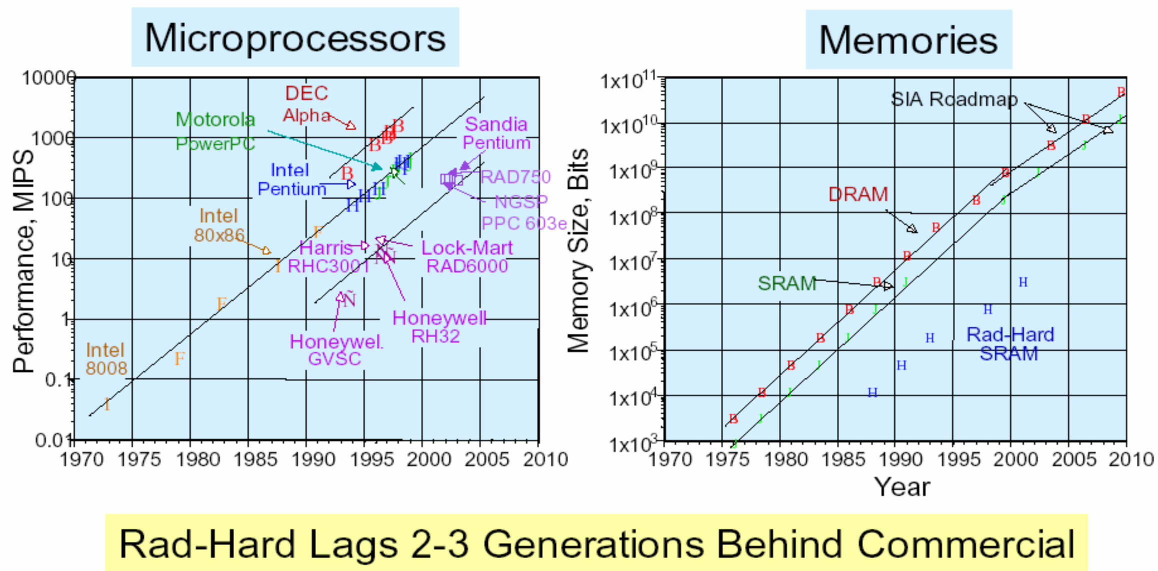
Fixed Mission/Science Capabilities

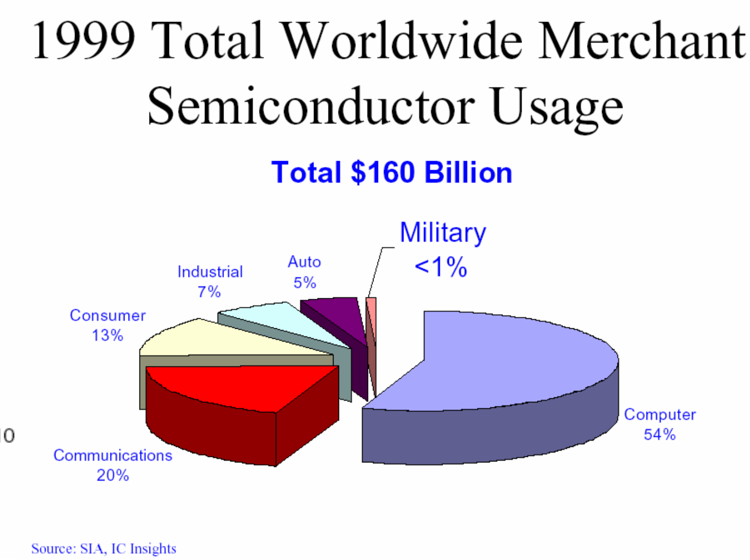
- **Most satellites are commissioned and designed to operate for 1-12 years and to meet a specific science and/or national mission needs**
- **For longer missions, it is possible that:**
  - The political environment changes, causing a change in potential threats or mission scope
  - The science changes, causing a change in algorithms that are needed for processing information
  - The satellite is damaged, causing a change in satellite capability
- **Most satellites can upload new software, but hardware is static in nature**
  - “Heroic” changes in the satellite could cause irreparable damage
- **Current solution is to launch new satellites**

Multi-dimensional Optimization Problem

- **Most satellite/avionics designers are trying to optimize performance, reliability, power, thermal and weight with fixed hard limits on power, thermal, reliability and weight from the mission requirements**
  - As stated by one group member, “There is never enough power or cooling.”
  - Another group member gave examples of how the limits set up by the mission requirements forced their design team into an expensive design space, because the mission requirements included an unknown 10x design margin
- **As stated before, changes along one dimension can affect all of the other dimensions and each dimension is designed by different teams with different skill sets manually.**

Widening Gap Between Mil/Aero and Commercial Devices





- **Rad-hard space technologies lag commercial technologies by 10 years.**
- **Existing defense and space semiconductor markets are becoming unviable.**
  - Defense-related space small % of semiconductor market
  - Disappearing rad-hard foundries (2 digital/2 analog)
  - Eroding rad-hard market: commercial space weak, low volume demand
- **One Mil/Aero roadmap indicated that it take until 2022 to fabricate a Rad-hard FPGA of the same size as a 2006 commercial FPGA**
- **Recent push to use trusted foundry parts are forcing satellite designers toward Mil/Aero parts**

Design for Worst-Case Environment

- **Many satellites are expected to endure years in a harsh radiation environments, with rapid temperature cycling, and an initial intense vibration**
- **The radiation reliability team is responsible for determining whether the parts can handle years of the average-case, worst-case, and possibly manmade radiation environments**
  - There could be 10-100 difference between the average-case and worst-case radiation environments
  - No wiggle room for many satellites on the manmade radiation environment
  - While there are tools available for determining the average-case and worse-case radiation environments, not all researchers use the tools in the same way.
  - Mission requirements are often written to worst-case scenarios – interactions with highly energetic particles that might be statistically infeasible, or to a fluence that could be impossible to test to
- **Because there are not enough in-the-loop space weather monitors, many satellites do not adapt to take advantage of the good weather days**

Testing Bottleneck

- **Many organizations will do (or pay someone else to do) initial static testing to determine worst-case reliability calculations in an attempt to eliminate parts that will not meet mission requirements or be too difficult to work with**
  - The advantage of working with mil/aero parts, heritage parts, or previously tested parts is that initial phase can be eliminated or minimized
  - If your team wants to use commercial parts, your organization could end up having to do all of the initial testing
- **In recent years, dynamic testing to determine workload-specific reliability has become more necessary and more complex**
  - If poorly managed, the radiation reliability team could end up living at their favorite accelerator
  - For some devices, fault injection has been helpful once the process was validated to predict accelerator results
- **Inadequate/incomplete testing can lead to a false security**

System Reliability Is Not Considered a Tractable Problem

- **System reliability is often considered intractable, so the focus is on part reliability**
  - This problem percolates through the entire process from requirements to design to integration
  - While part-specific error mitigation methods can be useful and should be encouraged, there are only a few point solutions available for solving reliability problems at a system level
- **The side effects of this situation are that it…**
  - Keeps the community focused on "problem parts" and mitigation solutions for those parts
  - Encourages wide "margin of error" design practices that can lead to slow, heavy, power-hungry, and expensive solutions

Possibly Interesting Solutions/Discussion Points

- **Modeling tools**
- **Agile satellite solutions**
- **Multi-core solutions**

Modeling the (performance, reliability, power, thermal) tradespace

- **Encapsulate the information from the devices so that designers can work at the system level**
- **Modeling tools that could help designers manage the complexity of:**
  - The memory architecture that provides solutions for known device sensitivities
  - System reliability analysis
  - (Reliability, Performance, Power, Temperature) optimization
  - Methods for managing multiple reliability problems
  - Simulation of lifetime aging problems
  - “Day in the Life” simulations

Agile Satellite Solutions for Better Reliability

- **Adaptive reliability solutions**
  - By linking satellites to radiation monitoring systems (either in the loop or data updates from ground stations), the spacecraft should be able to adapt to changing space weather conditions once a threshold for corrective action is met
- **Multi-level reliability solutions**
  - Software-based hardware checking for fault tolerance (Hubble servicing mission)
  - Reconfiguration to adapt to space weather, lifetime aging, science changes
- **Autonomous analysis tools and methods for assuring continued functionality**

Multi-Core Solutions that Address a Wide Application Space

- **No idea of common failure modes – unusually large SEFI cross-sections?**
- **Architecture solutions that optimize algorithms for its feature set**
- **Software for data processing vs. porting existing code base solutions**
- **Fault tolerant and Security solutions (tile isolation)**

Conclusions

- **Aerospace community dually bound by reliability problems and being culturally conservative**
- **The challenge problems this group is struggling with are leading to expensive, heavy, power-hungry, manual aerospace solutions**