National Aeronautics and Space Administration

Implementing the Next Generation of NASA Class D Missions – Radiation Engineering Considerations for Higher-Risk Missions

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Acronym Definitions

3-D	3-dimensional		**MIDEX**	Medium-Class Explorers
ADC	Analog-to-Digital Converter		**MIPS**	Million Instructions Per Second
CMOS	Complementary Metal Oxide Semiconductor		**MRO**	Mars Reconnaissance Orbiter
COTS	Commercial-Off-The-Shelf		**NASA**	National Aeronautics and Space Administration
CRM	Continuous Risk Management		**NPR**	NASA Procedural Requirement
CSLI	CubeSat Launch Initiative		**NPSL**	NASA Parts Selection List
EEE	Electrical, Electronic, and Electromechanical		**NRE**	Non-Recurring Engineering
ESSP	Earth System Science Pathfinder		**POF**	Physics of Failure
GSFC	Goddard Space Flight Center		**RIDM**	Risk-Informed Decision Making
HST	Hubble Space Telescope		**SCD**	Source Control Drawing
IC	Integrated Circuit		**SEE**	Single-Event Effects
ISS	International Space Station		**SMEX**	Small Explorers
JIMO	Jupiter Icy Moons Orbiter		**SWaP**	Size, Weight, and Power
JWST	James Webb Space Telescope		**TID**	Total Ionizing Dose
MER	Mars Exploration Rover			

Outline

- NASA definition of a Class D mission/payload
  - NPR 8705.4 (Risk Classification for NASA Payloads)
- Where \$20M ≤ *x* ≤ \$200M
  - The landscape of potential Class D missions is very broad.
    - CubeSats, technology demonstrations, satellite clusters, and high-dollar science
- Radiation assurance for commercial electronic components
- Testing at the board or box level
- Discussion and summary

NPR 8705.4 – Payload Risk Appendix B

Characterization	Class A	Class B	Class C	Class D
Priority (Criticality to Agency Strategic Plan) and Acceptable Risk Level	High priority, very low (minimized) risk	High priority, low risk	Medium priority, medium risk	Low priority, high risk
National significance	Very high	High	Medium	Low to medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Mission Lifetime (Primary Baseline Mission	Long, >5years	Medium, 2-5 years	Short, ~2 years	Short < 2 years
Cost	High	High to medium	Medium to low	Low
Launch Constraints	Critical	Medium	Few	Few to none
In-Flight Maintenance	N/A	Not feasible or difficult	Maybe feasible	May be feasible and planned
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities
Achievement of Mission Success Criteria	All practical measures are taken to achieve minimum risk to mission success. The highest assurance standards are used.	Stringent assurance standards with only minor compromises in application to maintain a low risk to mission success.	Medium risk of not achieving mission success may be acceptable. Reduced assurance standards are permitted.	Medium or significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.
Examples	HST, Cassini, JIMO, JWST	MER, MRO, Discovery payloads, ISS Facility Class Payloads, Attached ISS payloads	ESSP, Explorer Payloads, MIDEX, ISS complex subrack payloads	SPARTAN, technology demonstrators, simple ISS, express middeck and subrack payloads, SMEX

NPR 8705.4 – Mission Assurance Requirements Appendix C

Characterization	Class A	Class B	Class C	Class D
EEE Parts (https://nepp.nasa.gov/npsl)	NASA Parts Selection List (NPSL)* Level 1, Level 1 equivalent Source Control Drawings (SCDs), and/or requirements per Center Parts Management Plan.	Class A requirements or NPSL Level 2, Level 2 equivalent SCDs, and/or requirements per Center Parts Management Plan.	Class A, Class B or NPSL Level 3, Level 3 equivalent SCDs, and/or requirements per Center Parts Management Plan.	Class A, Class B, or Class C requirements, and/or requirements per Center Parts Management Plan.

- Note that this is strictly based on mission priority and significance, but has no delineation based on electronic system criticality or environment exposure.

Assurance, Reliability, and Availability for Electronic Devices

- Assurance is knowledge of (1) the supply chain and manufacturer of the product, (2) the manufacturing process and its controls, and (3) the physics of failure (POF) related to the technology.
- Reliability is the ability of a system to perform its required functions under stated conditions for a specified period of time.
- Availability is the proportion of time a system is in a functioning condition. This is often described as a *mission capable rate*.
- Does it *have* to work or do you *want* it to work?

Implications for EEE Parts

- The more *understanding* you have of a device's failure modes and causes, the higher the *confidence* level that it will perform under the mission environment and required lifetime.
  - *High confidence* = "have to work"
    - The key is problem-free part operation when required (appropriate availability over the mission lifetime).
  - *Less confidence* = "want to work"
    - The confidence in availability is not as high, or even known. This does not imply that the parts will not function as intended.
- Standard way of doing business
  - Qualification processes are thorough statistical characterizations designed to understand/remove known reliability risks and uncover unknown risks inherent in a part.
    - The method requires large sample sizes and comprehensive suites of piece-part testing (insight) designed to yield high confidence in part performance.

Screening *vs.* Qualification

- Electronic component *screening* uses environmental stresses and electrical testing to identify marginal and defective components within a "lot" of devices.
  - This is opposed to *qualification*, which is usually a suite of harsher tests (often destructive) intended to fully determine reliability characteristics of the device over a standard environment or application range.
- What is a "lot"?
  - For the military/aerospace system, it is devices that come from the same wafer diffusion processing group (*i.e.*, usually silicon from the same boule).
  - For all others, it is usually the same "packaging" date.
    - In this case, the silicon may or may not be the same, but the devices were packaged at the same time. This raises a concern often known as "die traceability."
  - *Device failure modes often have variance from silicon lot to silicon lot.*

Part Selection Tradespace

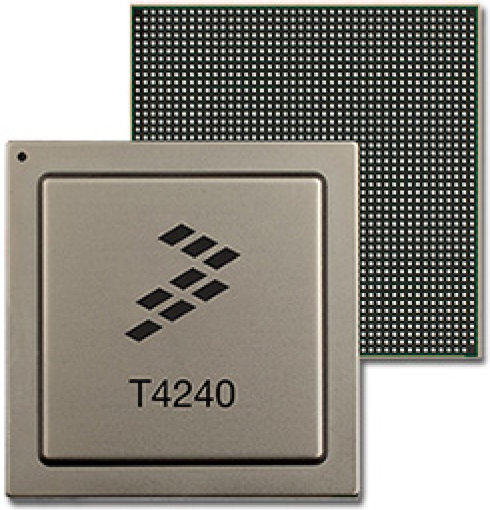
- Evolution of IC space procurement philosophy
  - The **OLD** approach was to only buy military/aerospace radiation hardened devices.
  - The **NEW** approach is to develop fault/radiation tolerant systems.
- Current parts selection processes now relies on systems design that involves a risk management approach that is often quite complex.
- For the purposes of this discussion, we define ICs in two basic categories:
  - *Space-qualified*, which may or may not be radiation hardened, and,
  - *Commercial*, which includes automotive components.
- Understanding risk and the trade spaces involved with these devices is the new key to mission success.
  - Size, weight, and power (SWaP) plus cost, for instance

"Teardown: Inside Apple's iPhone 5"

http://www.eetimes.com/document.asp?doc_id=1262563

Performance Requirements

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



Performance
Freescale QorIQ 12-core processor
http://www.ghs.com/news/20130423_DW13_freescale_qoriqT4242.html

Programmatic Requirements and Considerations

- Rationale
  - Trying to keep a program on schedule and within budget
- Personnel involved
  - Project manager, resource analyst, system scheduler, and *product development leads*
- Usual method of requirements
  - Flowdown from parent organization or mission goals for budget and schedule
    - Launch date, for example
- Buzzwords
  - Cost cap, schedule, critical path, risk matrix, contingency
- Limiting factors
  - Parent organization makes final decision

Programmatics

http://www.dreamstime.com/stock-images-old-fashion-cash-register-image1247464

Understanding Risk

- Risk management requirements may be broken down into three categories:
  - Technical/Design – "The Good,"
    - For example, 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 – "The Bad," and
    - For example, a mission missing a launch window or exceeding a budgetary cost cap, which can lead to mission cancellation
  - Radiation/Reliability – "The Ugly."
    - Relates to mission meeting its lifetime and performance goals without premature failures or unexpected anomalies
- Each mission must determine its own priorities among the three risk types.

http://www.forbes.com/sites/glennllopis/2011/04/04/why-risk-must-be-your-best-friend-in-todays-business-climate/

Risk Tradespace – Some Considerations for Device Selection

- Cost and schedule
  - Procurement
  - NRE
  - Maintenance
  - Qualification and test
- Performance
  - Bandwidth and density
  - SWaP
  - System function and criticality
  - Other mission constraints (*e.g.*, reconfigurability)
- System complexity
  - Secondary ICs (and all their associated challenges)
  - Software, *etc.*
- Design environment and tools
  - Existing infrastructure and heritage
  - Simulation tools
- System operating factors
  - Operate-through for single events
  - Survival-through for portions of the natural environment
  - Data operation (example, 95% data coverage)
- Radiation and reliability
  - SEE rates
  - Lifetime (TID, thermal, reliability,…)
  - "Upscreening"
- System validation and verification

NASA and COTS Parts

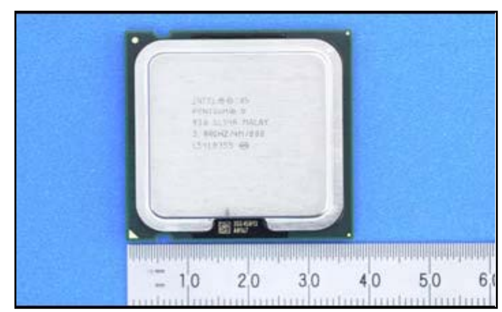
- NASA has been a user of COTS electronics for decades, *typically* when
  - Military and aerospace alternatives are not available (performance or function or procurement schedule),
  - A system can assume possible unknown risks, and,
  - A mission has a relatively short lifetime or benign space environment exposure.
- In most cases, some form of "upscreening" has occurred.
  - It is a means of measuring a portion of the inherent reliability of a device.
    - Discovering that a COTS device fails during upscreening has occurred in almost every flight program.

Why COTS?
Growth in IC Availability

- Over the last several decades, the semiconductor industry has seen an explosion in the types and complexity of devices that are available.
  - The commercial market drives features, such as
    - High density (memories),
    - High performance (processors),
    - Upgrade capability and time-to-market,
    - Wireless (radio frequency and mixed signal), and
    - Long battery life (low-power CMOS).

Zilog Z80 Processor
circa 1978
8-bit processor

Processor pictures courtesy
NASA/GSFC, Code 561



Intel 65 nm Dual Core Pentium D Processor
circa 2007
Dual 64-bit processors

Suggested EEE Parts Usage Factors

Environment/Lifetime

Criticality	**Low**	**Medium**	**High**
Low	COTS upscreening/ testing optional; do no harm (to others)	COTS upscreening/ testing recommended; fault-tolerance suggested; do no harm (to others)	Rad hard suggested. COTS upscreening/ testing recommended; fault tolerance recommended
Medium	COTS upscreening/ testing recommended; fault-tolerance suggested	COTS upscreening/ testing recommended; fault-tolerance recommended	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.
High	Level 1 or 2 suggested. COTS upscreening/ testing recommended. Fault tolerant designs for COTS.	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.	Level 1 or 2, rad hard recommended. Full upscreening for COTS. Fault tolerant designs for COTS.

Component "levels" are defined in EEE-INST-002 (https://nepp.nasa.gov/index.cfm/12821).

Comments on Matrix Wording

- "Optional" implies that you might get away without this, but there's risk involved.
- "Suggested" implies that it is a good idea to do this.
- "Recommended" implies that this really should be done.
- Where just the item is listed (like "full upscreening on COTS"), this should be done to meet the criticality and environment/lifetime concerns.

Good mission planning identifies where on the matrix it lies

Cost-Saving Suggestions for Payloads on a Budget

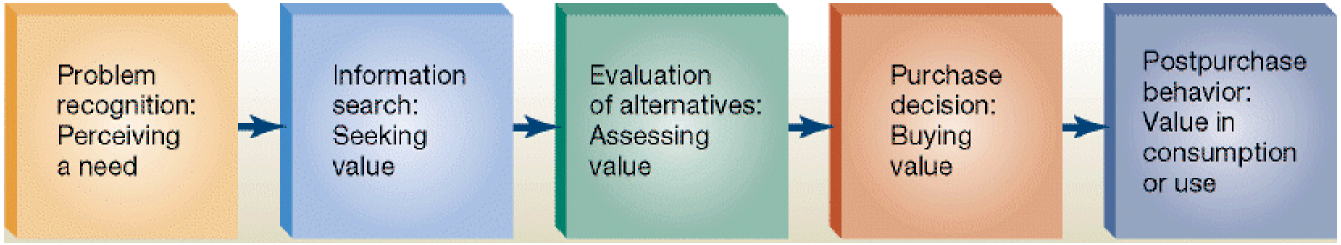
- First and foremost, *scrounge* for parts.
  - Are there spare devices available at either your location or elsewhere?
  - Some parts may be fully screened and even be radiation hardened/tested.
    - You may still have to perform some additional tests, but it's cheaper than doing them all!
- Engage EEE parts *and* radiation engineers early to help find and evaluate designers' "choices."
  - Use their added value to help with the choices and even on fault tolerance approaches; you'll need them to "sign off" eventually.
- If you can't find spares, try to use parts with flight heritage.
  - At a minimum, the hope is that your lot will perform similarly to the "history" lot – though this is not guaranteed.
  - Though it's riskier, you can choose devices built with the same design rules by the same company (*i.e.*, different part, but on the same process/design as a part with "history").
- If you absolutely need something new, you will pay for the qualification or take the risk.
  - Note that in the case of risk acceptance, the amount of risk may not be quantifiable.

Risk Reduction Cost Estimation Considerations

- Cost-saving measures are best implemented up front.
  - Conduct a thorough examination of the radiation environment.
  - Develop flexible radiation requirements (parameterize them).
  - Negotiate a budget for one or more 3-D radiation ray trace studies.
  - Ensure that radiation engineering is programmatically tied to electronic component approval (*e.g.*, voting member of parts control board(s)).
    - Will affect level of effort in preliminary and final design phases
    - Ensures ability to continually manage risk
- Ability to conduct ground-based radiation testing may be compromised due to cost and schedule constraints.
  - Are there suitable requirement relief mechanisms built-in, or will estimated costs and unknown risks have to be used as leverage?

Summary

- In this talk, we have presented considerations for selection of ICs, focusing on COTS for space systems.
  - Technical, programmatic, and risk-oriented
    - As noted, every mission may view the relative priorities between the considerations differently.
- As seen below, every decision type may have a process.
  - It's all in developing an appropriate one for your application and avoiding "buyer's remorse"!



Five stages of Consumer Behavior

http://www-rohan.sdsu.edu/~renglish/370/notes/chapt05/

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