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SOC SEE Qualification Guideline & iPad Radiation Test Results

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Outline

- SOC SEE Guideline
  - What it is & why
  - Structure of the guideline
  - Samples from some sections & recommendations
  - Current status
- iPad Radiation Test Results
  - Intro/Background & Test Approach
  - Results - Co-60 & Protons
- Conclusion

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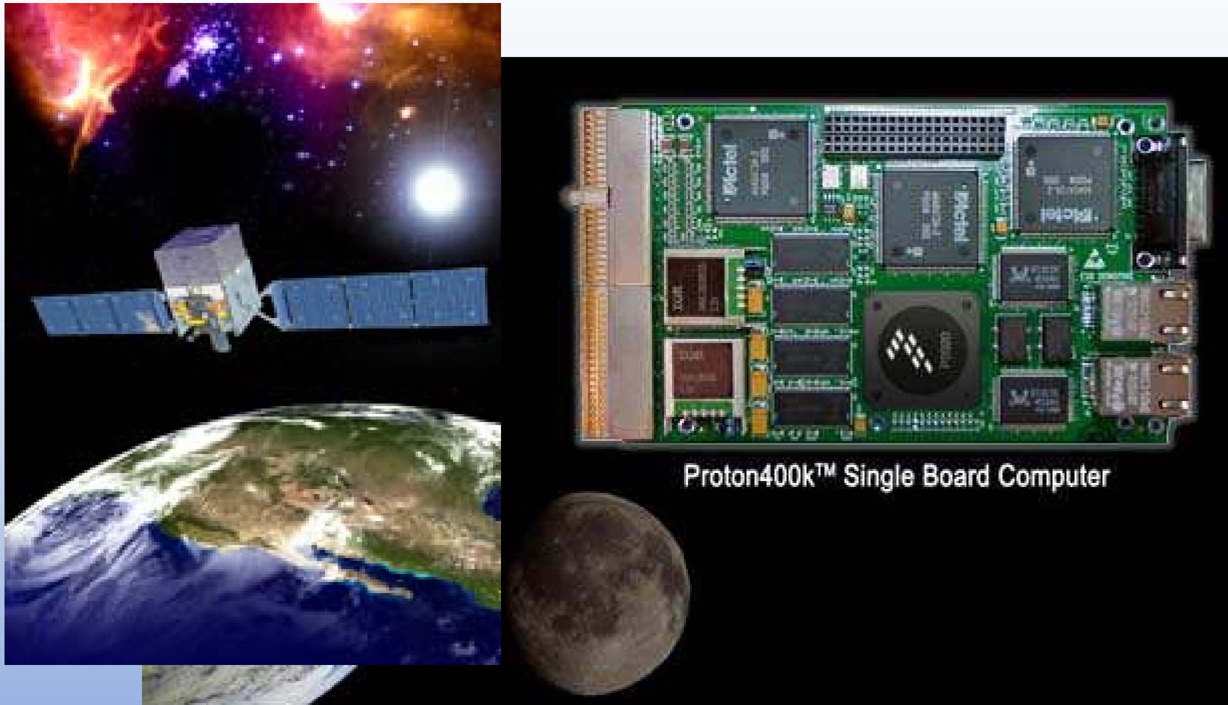
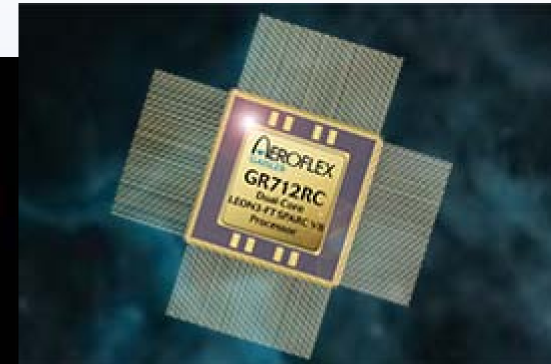




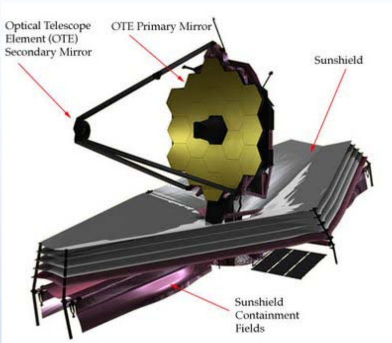
SOC SEE (RADIATION) GUIDELINE

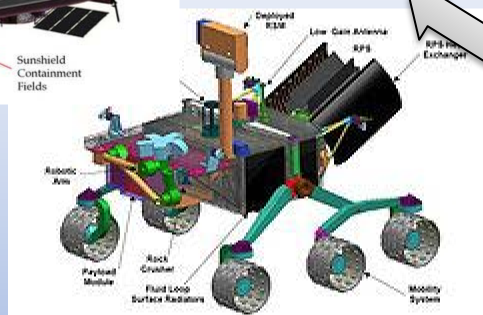
To be presented by Steven M. Guertin at the 4th NASA Electronic Parts and Packaging (NEPP) Program Electronic Technology Workshop June 11-12, 2013, NASA GSFC, Greenbelt, MD.

Motivation

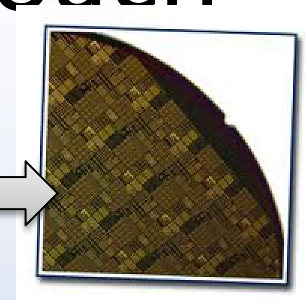
- Many space programs are using or designing around modern SOCs – i.e. Freescale P2020
- Space part manufacturers are providing RHBD SOCs – i.e. Aeroflex UT699, BAE e5500-based microprocessors
- JPL microprocessor SEE guideline (Irom, 2008) needs update for modern SOC devices.
  – Very complex devices
  – Multiple elements – do all need to be tested?
  – Manufacturing processes impact test methods

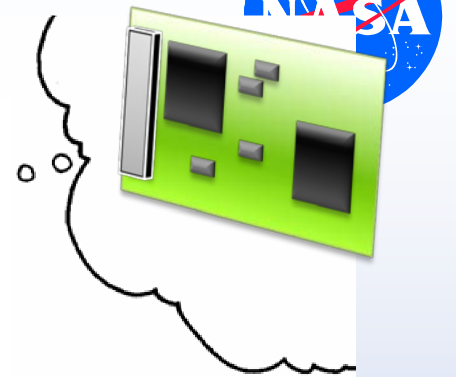
NEPP Approach





Users





Manufacturers

Testers

- Devices are too complex for full characterization
- Test methods must target basic information needed for manufacturers and provide useful information for users to be aware of and/or mitigate radiation effects
- This approach seeks to provide the information necessary to understand the most important radiation effects for a given system, utilizing manufacturer assistance, and targeting actual application needs.

Focus Areas for Guideline

- Collaboration with Manufacturers and Users
- On-Chip Peripheral Approach/Prioritization
- Fault Tolerant Device Test Approaches
- RHBD Device Challenges to Test Development
- Multicore Device Unique Challenges
- General Test Methods
- Collecting Results from Sample Testing

Structure of SOC SEE Guideline

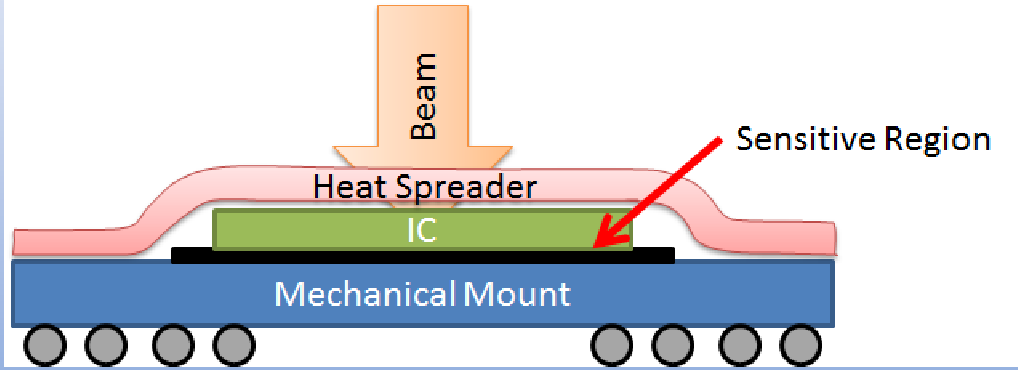
- Covers key areas of test planning, development, and performance:
  - Determining the type of radiation testing needed or possible
  - Development of hardware, software, and test procedures
  - Performance of testing and analysis of data
- Provides relevant examples
  - Freescale P2020 & P5020, Boeing Maestro ITC, Aeroflex UT699
- Provides specific recommendations for various elements of SEE testing of SOCs.

Needed Radiation Data

- Details to Consider:
  - Mission environment – see standard guidelines and mission specifications – generally may need proton and heavy ion data
  - SOC details (e.g. RHBD construction)
  - Program usage of the SOC
  - Tool that will be used for rate calculations
- SOC Details
  - Mechanical and thermal information – may impose range requirement
  - Trade study between custom hardware and inexpensive evaluation boards is recommended
  - Modern device feature size may warrant proton direct ionization testing
- Program usage
  - General testing may not be explicit enough for the user
  - But user must provide actual flight usage (unlikely till after launch)

Test Preparation

- Determination of appropriate test facility
  - Summarized: IUCF, UCD, Triumpf, TAMU, BNL, UCB, UCL, RADEF, NSRL
- Establish package materials and determine depackaging…



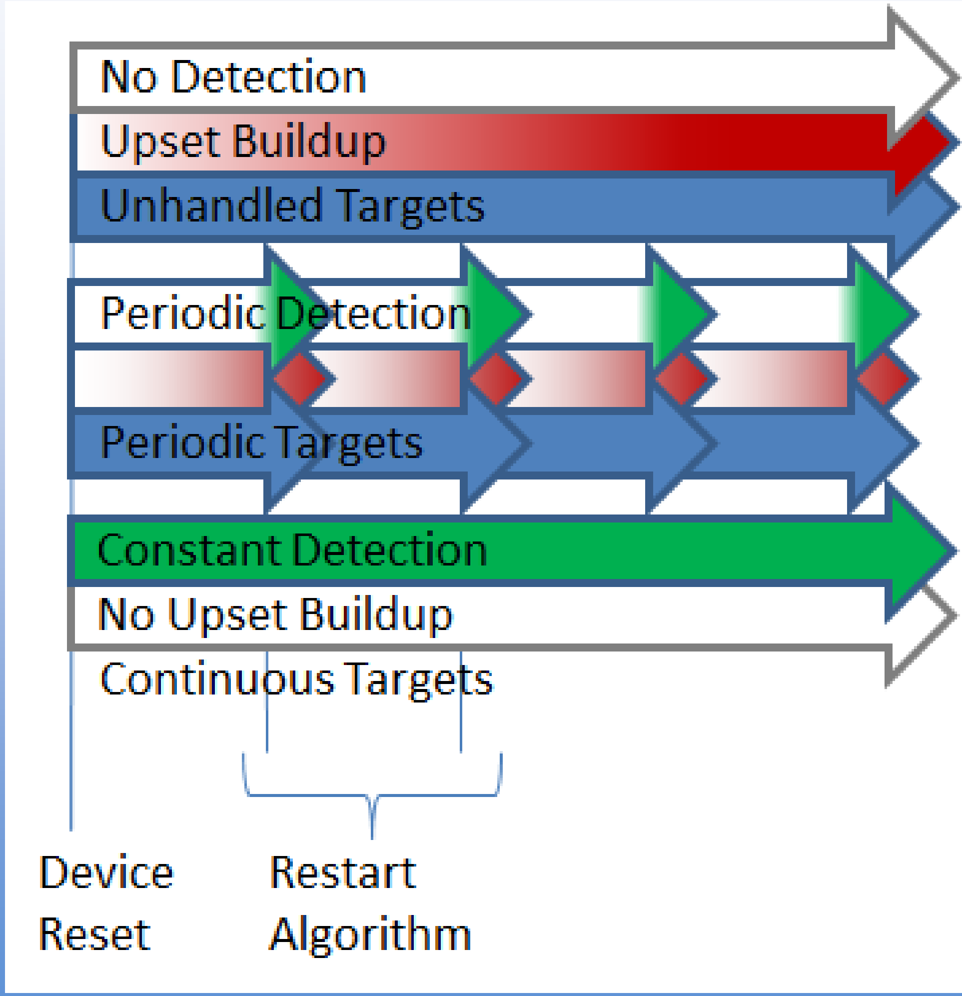
- Selection of DUT board – custom vs. inexpensive manufacturer evaluation board?
  - 10's of k vs. 0.5-4k
  - Note that lower-end evaluation boards may be sufficient (~0.5k)
  - Might be able to rework mfr board with socket

Keys to Test Algorithms - Structure

- Manufacturer equipment can perform SEE detection
  - Relatively easy to use
  - Limited ability to exercise the DUT
  - Difficult to automate
- Custom Algorithms
  - Recommend Assembly Language
    - Does not hide machine behavior or make assumptions about programming model (for example, C assumes a subroutine call structure and variable storage model)
    - Can make it difficult to debug, and may limit complexity of test algorithms

Test Algorithm Time Models

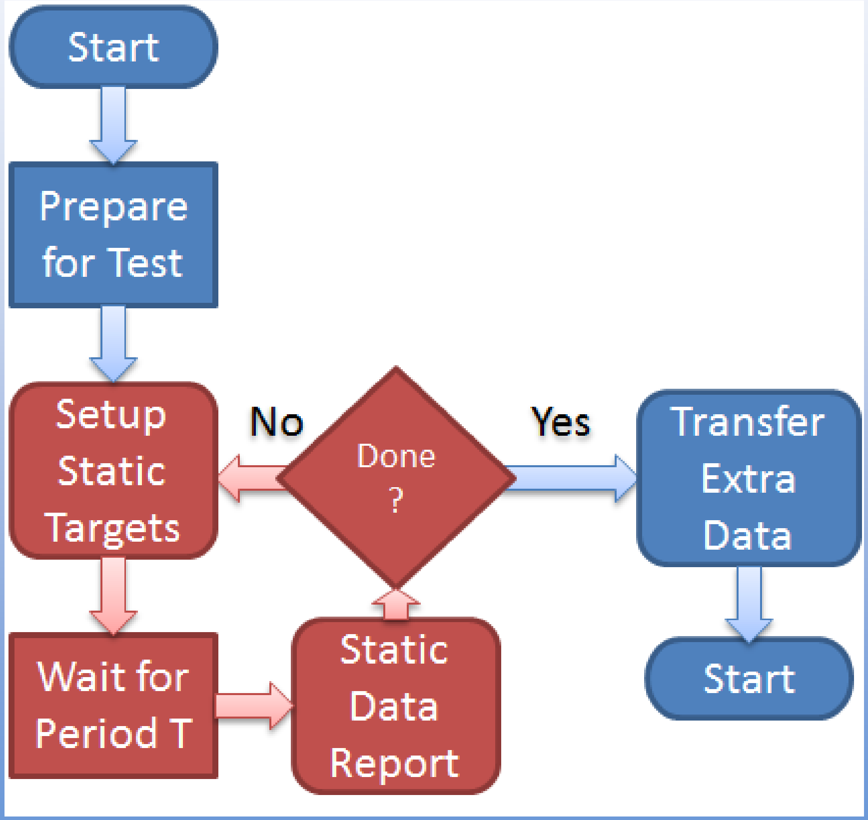
- Unhandled targets build upsets during exposure.
- Periodic targets build upsets during an integration phase
- Constant detection



Standard Static Soak Test

- Test algorithms are generally based on repeated sub-tests that may report on each loop iteration…

- Test algorithms should periodically report results to enable immediate detection of loss of operation.
- Periodic reporting enables use of partial runs.

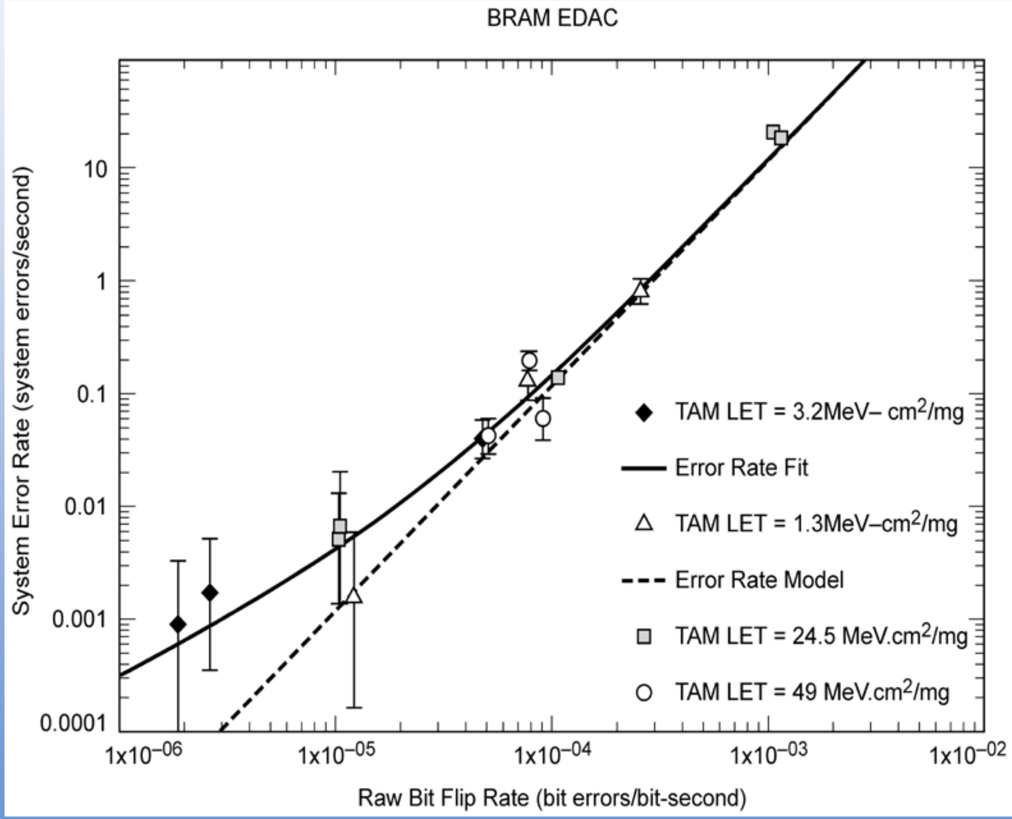


Keys to Test Algorithms - Anomalies

- It is common to want to explore test anomalies because they may be "rare SEEs". Avoid this want as it leads to much lost time.
- Rely on beam and event statistics. If it doesn't repeat, put a limit on it and move on. If it does repeat, figure out what it is if possible.
  - If you can't figure out what it is, that's ok. Report the rate, but don't claim a mechanism.
  - Be aware you may be exploring a bug in your code, or even upsets in support or test equipment.
- When possible, use debugging tools to examine these as they enable fast and detailed examination

Key Data to Collect

- DUT Preparation
  - Hardware modifications
  - Parameters of operation (V, T, I, f)
- # of observed events
  - Description of event
  - Details of code or test equipment that enables detection (machine-description if possible)
  - Details of event – algorithm dependence, throughput, FT/EDAC, etc
- # of incident particles
  - Species, energy/LET, angle of incidence
  - Structure of beam delivery (constant, Poisson, pulsed)



True FT protected element error rate follows dashed line. Real structure may have non-FT component leading to flattening.

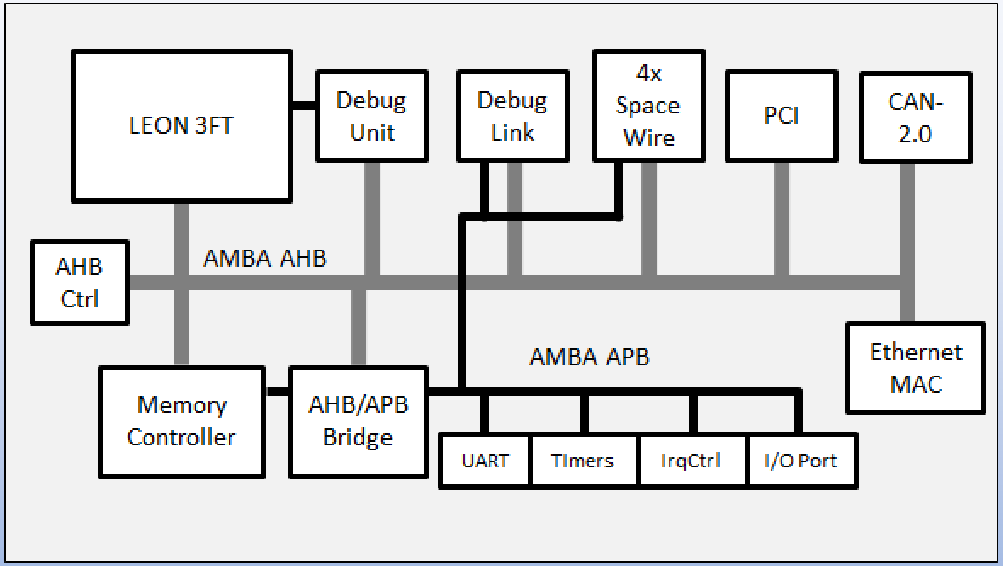
Testing – Avoiding Redundancy

- Many modern SOCs are constructed from SRAM or similar elements that are easily tested.
- But these elements are known to be weak to SEE, so they are protected with FT or EDAC. Thus characterization is largely unnecessary.
- It is also important to verify to FT, EDAC or other protection works.
- And it is important to avoid measuring sensitivity of these elements many times (though they can be good for establishing a baseline and test-to-test consistency).

Testing – Determine Sensitivity

- Because of the nature of SOC testing many different types of events can influence reported data.
- This necessitates determining the sensitivity of the test system for each event type investigated.
  - Determine the system response that establishes a “floor” to detection – for example if the DUT “crashes” (fails to continue proper execution) this generally means that any more rare event is undetectable.
- Sensitivity can be improved by either improving robustness of the test system or by targeting a given event type.

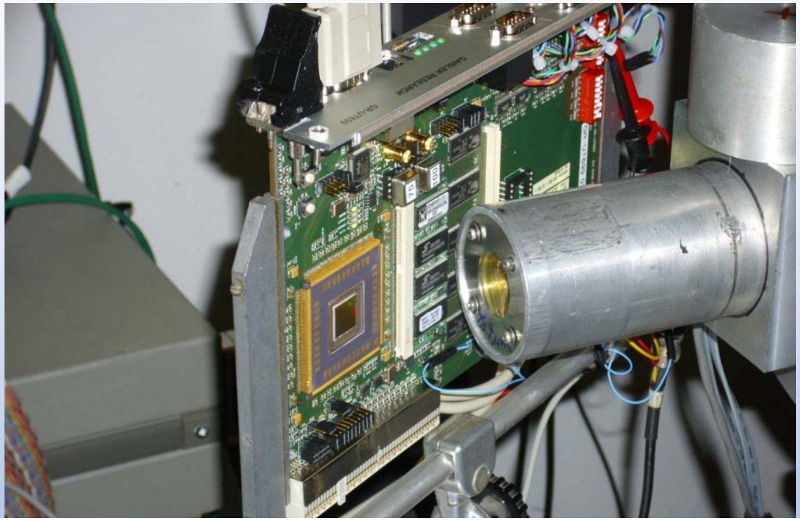
Example from UT699 - 1

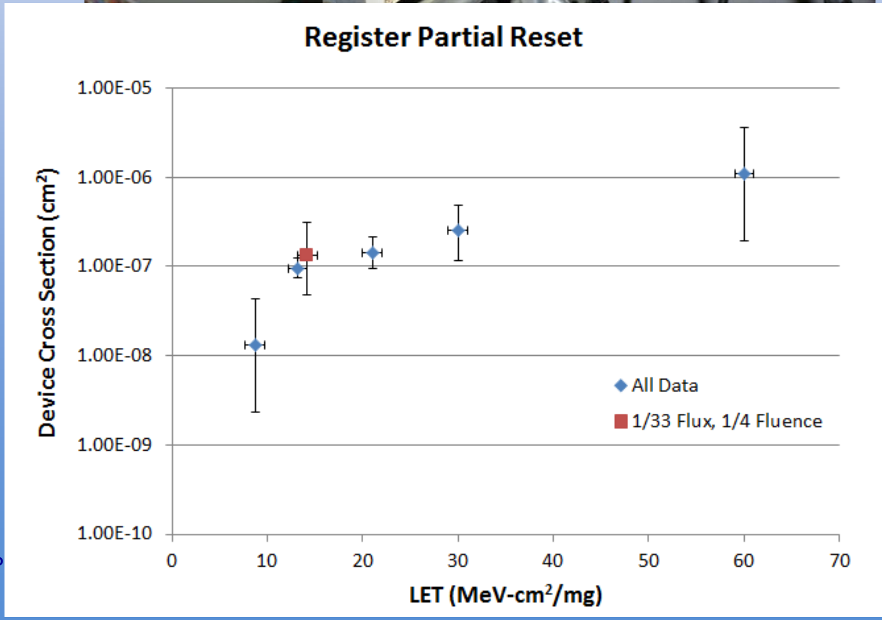


- Sparc V8 Leon 3FT core – desired by many space users
- RHBD with built-in FT
- Many different types of components
- Study includes "register partial reset" and Spacewire examination

Testing/Results

- Manufacturer involvement ensured successful DUT preparation and understanding of events
- Explored different types of flux and fluence dependence to lock-in on the register partial reset
- Spacewire results showed effective sensitivity was not sufficient to observe SEE: Spacewire is robust…





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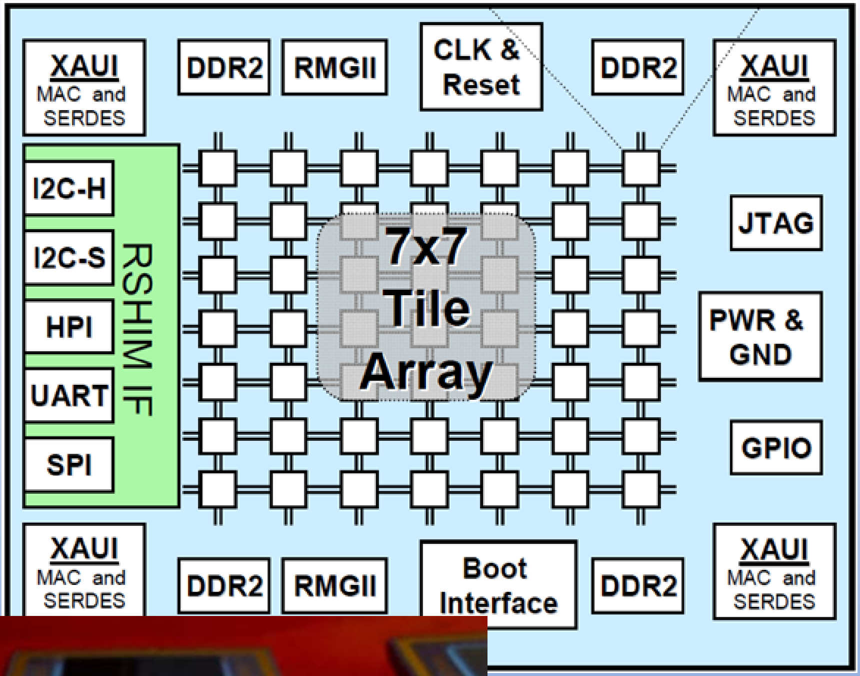
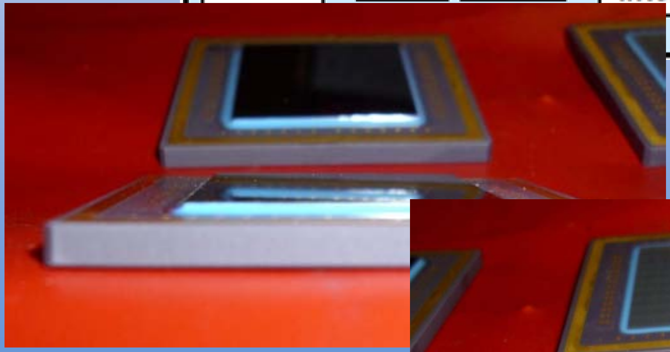
Example from Boeing Maestro ITC

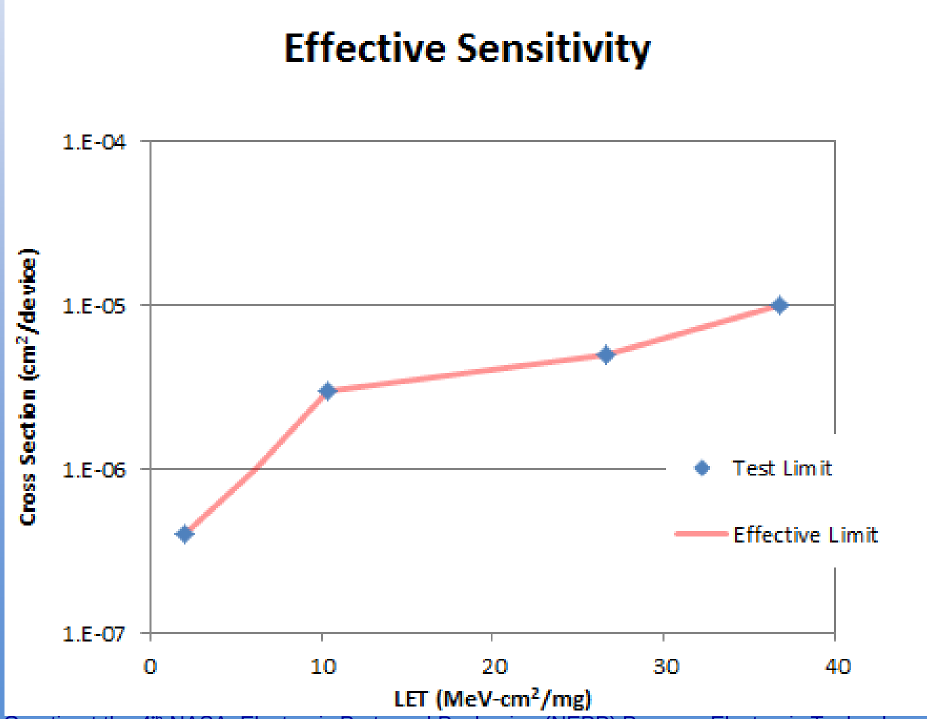
- 49-core tiled microprocessor
- RHBD and FT construction with SRAMs expected to upset readily (but they are EDAC protected)
- Highlights need for custom DUT preparation.





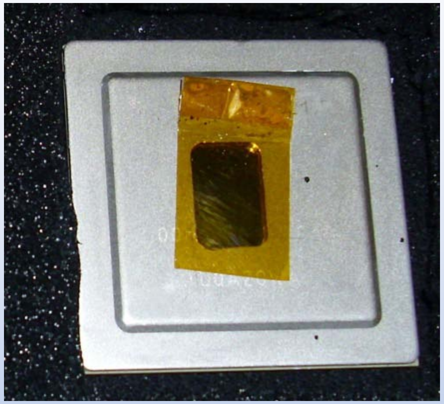
Test Efforts/Results

- Highlight of need to understand beam delivery and algorithm structure (algorithm behavior on multiple tiles potentially confusing).
- Effective sensitivity is a key player because the caches are very sensitive to SEEs and relatively high fluence is required to activate non-cache upsets. But in the meantime the caches are experiencing many SEUs.

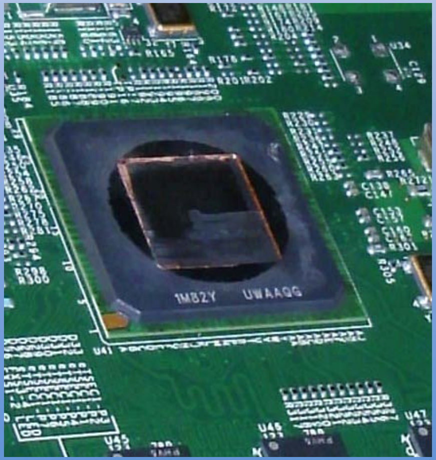


Example from Freescale - 3

- The P2020 and P5020 processors provided the best example of commercial/COTS type devices with the relevant testing issues.
  - Thermal issues and depackaging dominate
  - Cannot reliably test at many angles
- Debugging tools are well-developed
  - Codewarrior tool set is useful for directly observing what is wrong with the processor (provided it can successfully perform).



P5020 – with hole to expose e5500 cores



P2020 with hole in heat spreader

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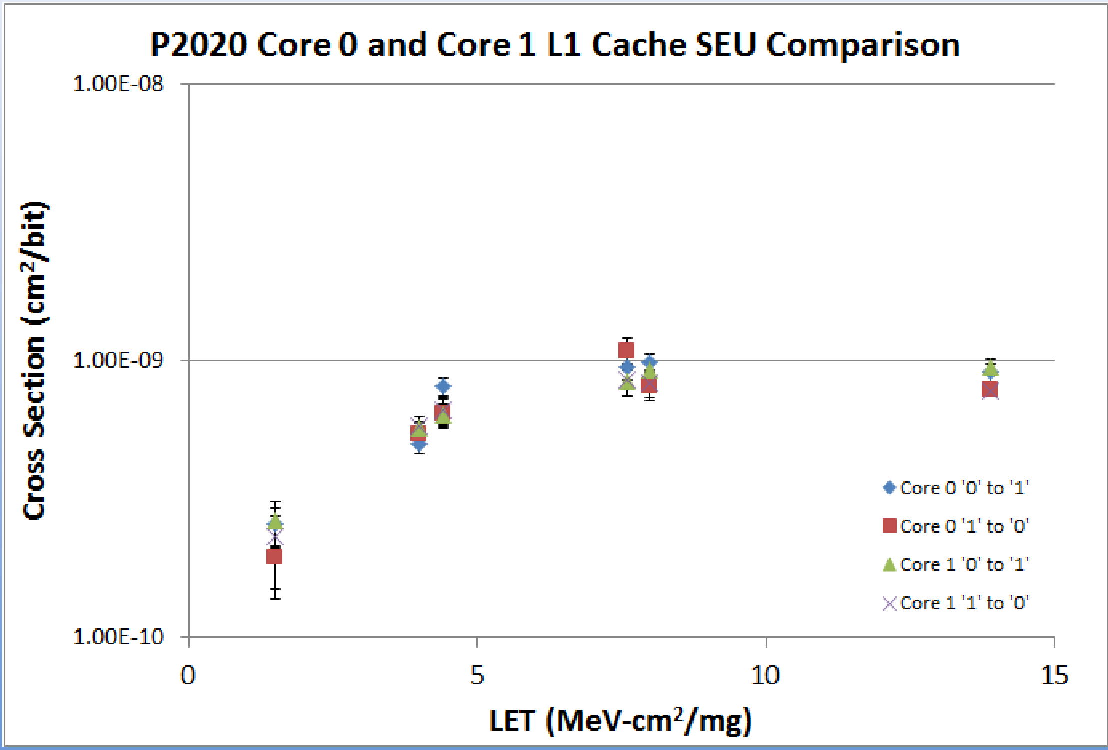
P2020 Provides Dual Core Environment…

- Multicore testing will gain in importance…
- P2020 provides cache-coherency for communicating data between processors
- Testing with both cores active shows cache sensitivity is essentially the same.



IPAD™ RADIATION TEST RESULTS

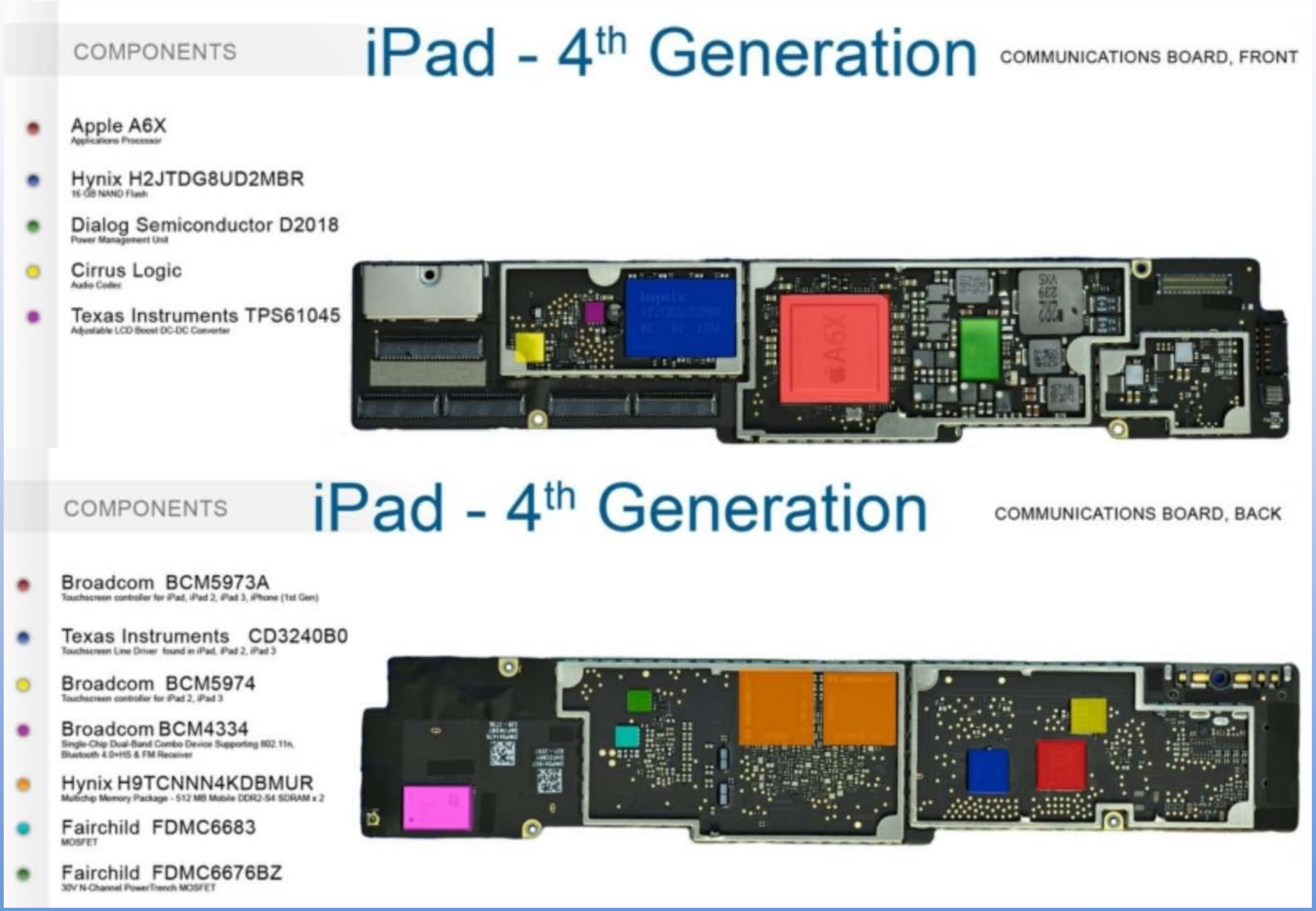
4th Generation iPad™ Testing

- Why?:
  - Explore the failure mechanisms of a complex system and evaluate how well we can perform a quick test.
  - Establish TID performance (possibly enabling later SEE testing)

General Info

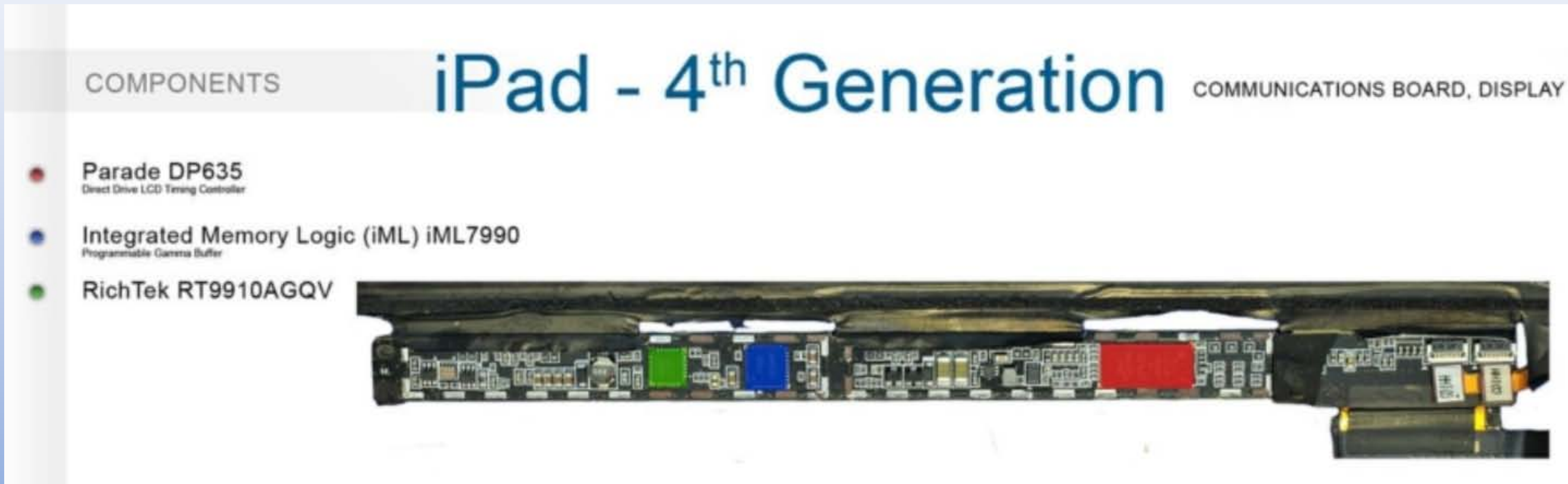
- iPad has more than 16 components of interest
- Teardown from eetimes and news.grouperly.com…

What's Inside



Slashgear, "iPad 4 teardown: More of the same (and a missed opportunity)", http://news.grouperly.com/news/ipad-4-teardown-more-of-the-same-and-a-missed-opportunity (11/2012)

What’s Inside



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Test Approach

- Basic test approach:
  - Characterize
  - Expose
  - Characterize
- Characterization includes using the following apps:
  - xSensor (accelerometers, magnetometers, GPS)
  - Test pattern to test the display
  - MP3 audio playback to test sound
  - Passmark's iPad benchmark for general benchmarking of processor, memory, flash, and 2D and 3D graphics
  - Observed power up and won, battery charging current, photographs of iPad output, and nominal operation of touchscreen

Exposure Position

- TID exposures done with JPL's high dose rate room irradiator
- Proton exposure conducted with UC Davis 63 MeV proton beam, using 7 beam spots

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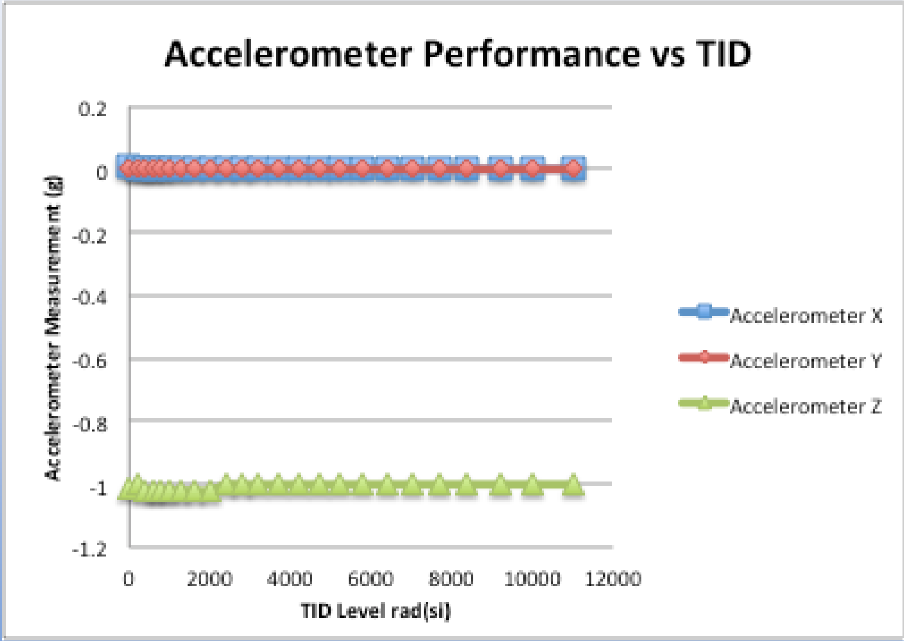
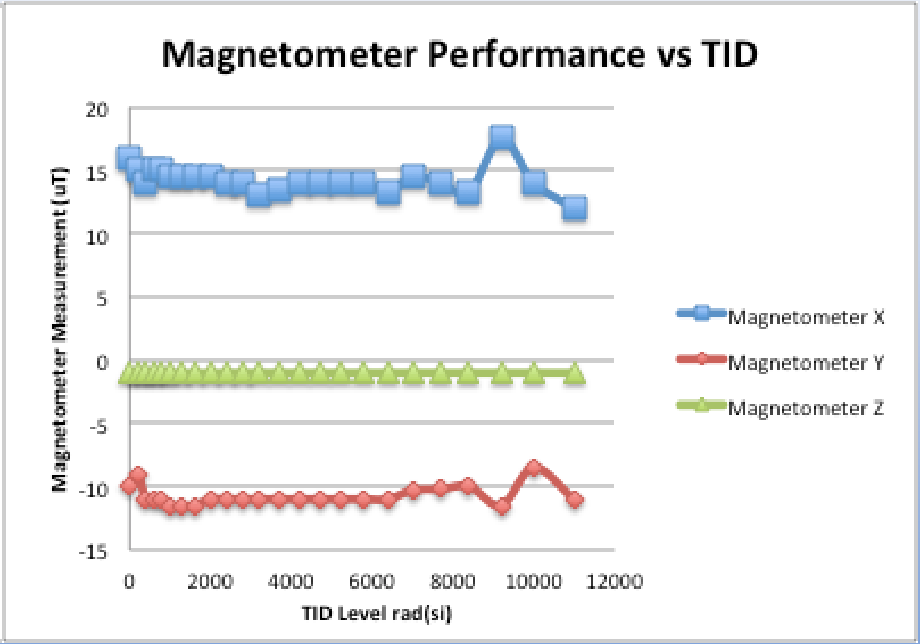
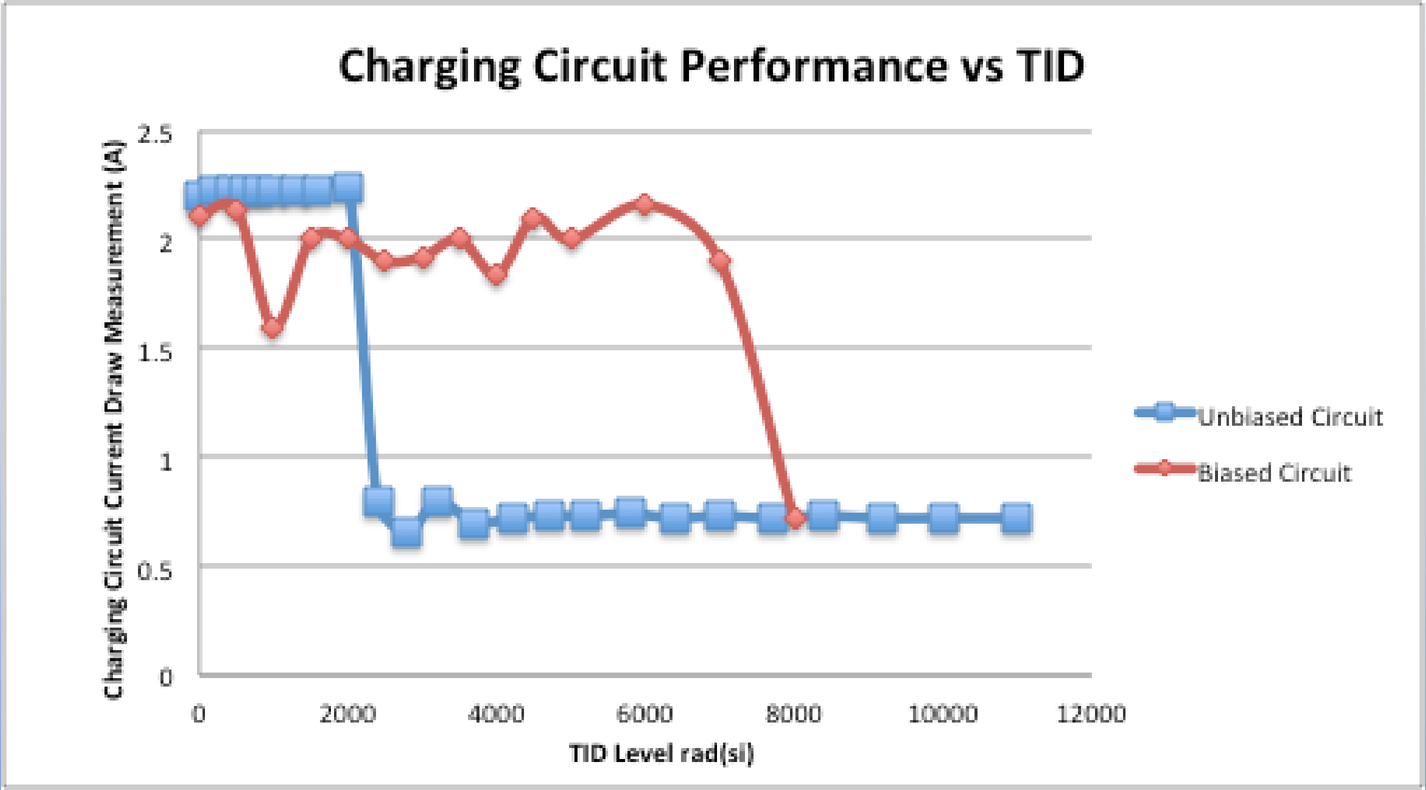
Nominal Results on Most Benchmarks/Characterization



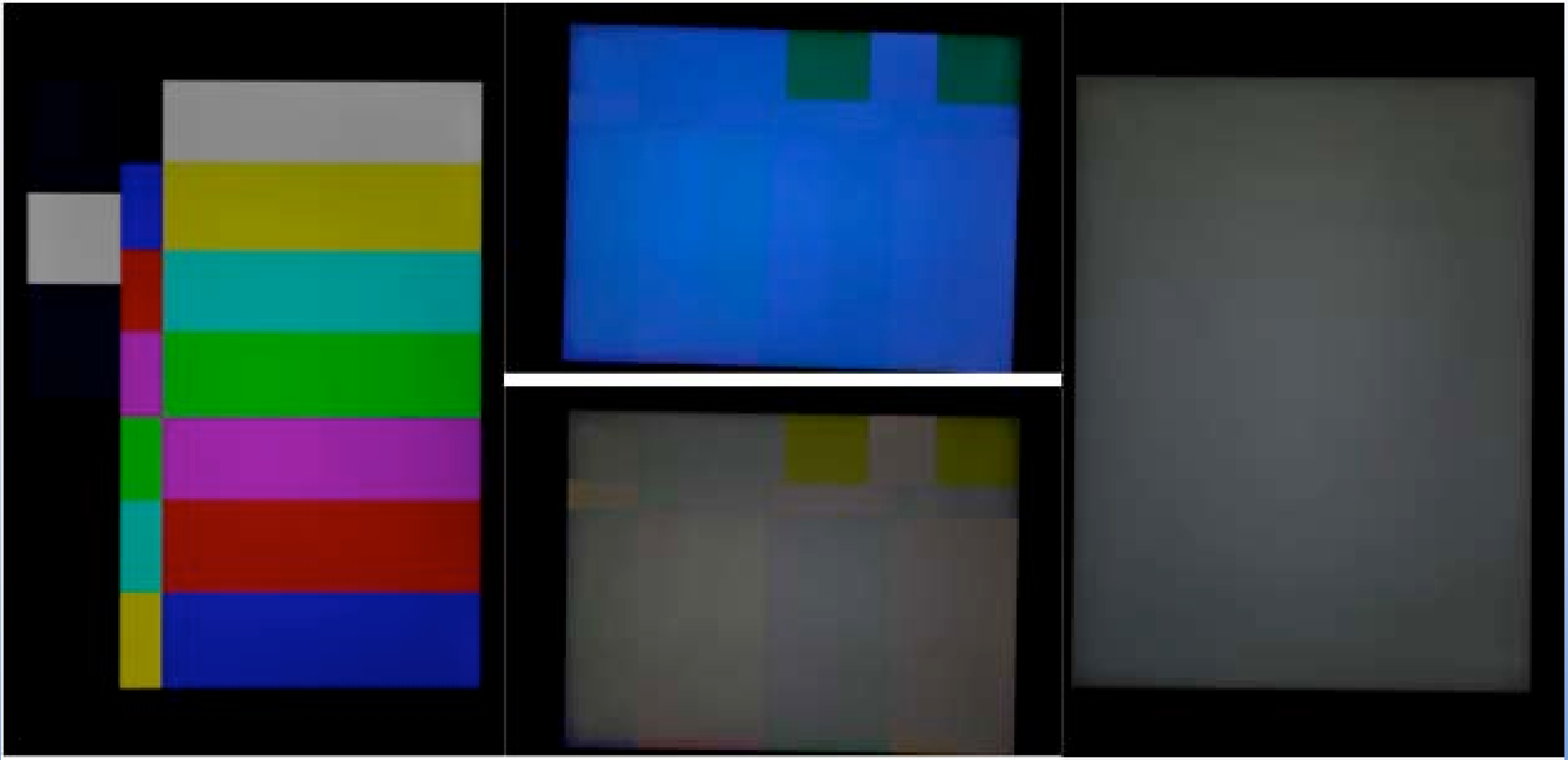


Changes in Charging



- TID performance of charging shown above for biased vs. unbiased
- Also observed changes in detected charge level (100 to 70% while unused)

Screen Degradation



- The iPad output to the screen degrades, failing at about 9 kRad biased and 11 kRad unbiased

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Observations – Shut Off

Observations – Camera Static

Summary of First Failures

- Total devices damaged: 6 (of 7 – only 1 still works)
  - Screen no longer usable: 1 – 8 kRad biased Co-60,
  - Charging circuit not working: 2 – 4 kRad unbiased Co-60 (next failure is screen at 11kRad); and 4kRad unbiased protons in positions A-C (next failure is screen between 8 and 12kRad)
  - Failed with no sign: 1 – 4 kRad biased protons in position C
  - Failed with infinite reboot behavior: 2 – one with 4 kRad delivered only to position D with protons; the other after 12 kRad delivered to A-D (device already passed with 20 kRad delivered to E and 8 kRads to A-D)
- Failures were not unexpected but could not have been predicted before testing.

CONCLUSIONS

Conclusion - I

- SOC Guideline addresses many of the problems with radiation testing of modern microprocessor systems
  - Test facilities, packaging/repackaging, realities of test board selection, software algorithms, debugging tools, data collection, data analysis, etc.
  - Information is presented and developed. Recommendations are explicitly called out in special sections.
  - Example data is presented from three general case studies
- SOC Guideline is in review and we are pushing for release soon
  - Excellent feedback from several organizations (more may come during release process)

Conclusion - II

- 4th Generation iPad™ studied as candidate for complex system response to radiation
  - System-level may be the way we head on certain types of complex devices in the future
- iPad testing has been conducted
  - Scope limited to TID (using Co-60 and protons)
  - (SEE on these devices may indicate where the SOC guideline goes with even more complex devices & systems)
- Co-60 and protons showed similar first failures
  - Charging circuit fails under unbiased irradiation at 4k (Co-60), and screen driver fails biased at 8k (Co-60 & proton)

- End

Testing – Recording the Test

- When possible, collect the following:
  - Facility test record
  - Test engineer test log
  - Power supply log files
  - All I/O logs between the DUT and support equipment (including key transfers to enable verification of commands)
  - SEE records stored during test and reported after the test completes