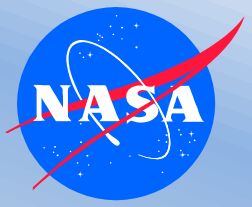
National Aeronautics
and Space Administration



SEE Testing of the Snapdragon 820: On-Site Annealing and POP Challenges

Steven M. Guertin, Sergeh Vartanian, and Matthew Cui

Jet Propulsion Laboratory / California Institute of Technology
Pasadena, CA

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology,
Under contract with the National Aeronautics and Space Administration (NASA)

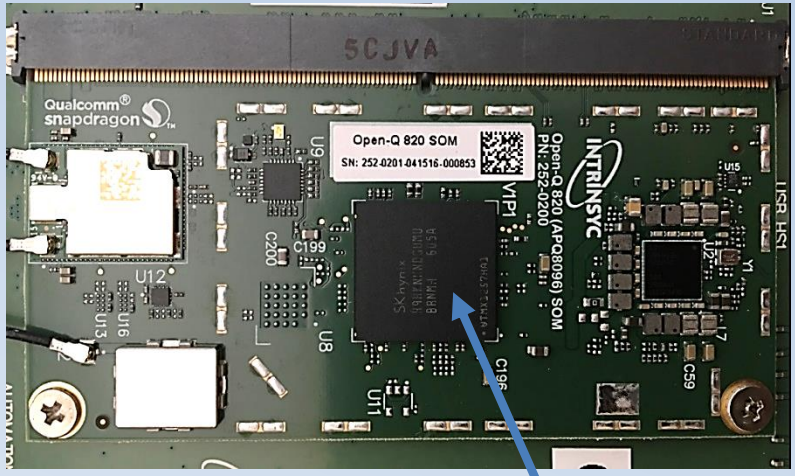
This work was sponsored by the NASA Electronic Parts and Packaging (NEPP) program. This work was supported by the Los Alamos Neutron Science Center (LANSCE) which provided neutron beam time under proposal NS-2016-7268-F. We appreciate the assistance of Steve Wender and Tanya Herrera for supporting this test. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

National Aeronautics
and Space Administration

Background

Why is the Snapdragon important?

- Snapdragon is a system-on-a-chip (SOC) and a complex processor
- Made on Samsung's 14nm low power plus (LPP) fabrication line
- High power to performance ratio make it attractive for space users on short missions, high risk tolerance, and low budget
- Testing was carried out TAMU (heavy ions), MGH (protons), and LANSCE (neutrons)



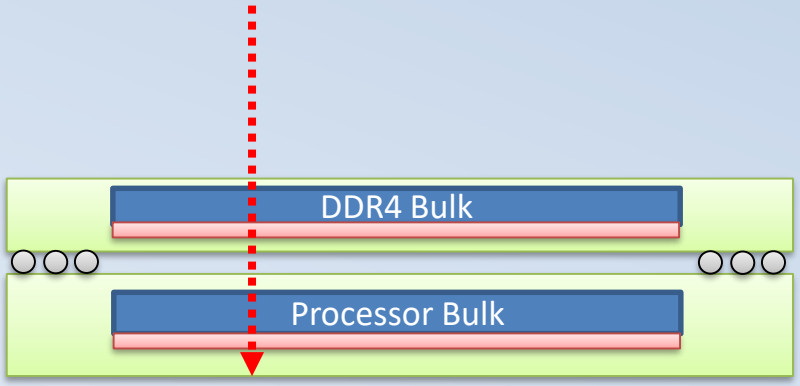
Intrynsic Open-Q Snapdragon 820 SOM

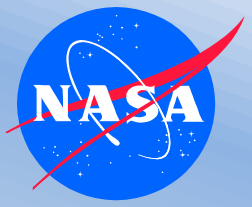
The processor is under the SK Hynix LP DDR4 device in the middle.

A heatsink is normally placed over the DDR4 device but was unnecessary provided good ventilation was available.

protons, neutrons, and 40 MeV/amu ions can penetrate to the processor structures…

- Particles must traverse DDR4 die and processor die to reach active region of processor
- Thinning of the DDR4 is not obviously beneficial – still have to have enough energy to get through the processor
- Approximate thicknesses:
  - DDR4 plastic ~200 um
  - DDR4 Die 200 μm
  - Processor upper plastic ~100 μm
  - Processor Die 250 μm
- Testing done at normal incidence





Snapdragon 820 SEE Test Plan

Device Information

- Device mounted in a package on package (POP) configuration that did not allow to directly observe chip
- Both Snapdragon and attached DDR4 device tested for heavy ions, protons, and neutrons
  - DDR4 device could not be removed without significant resources to operate the device outside normal configuration

Test System

- Powered with lab supply of 5 V to board
- DUT was connected by two USB ports to test computer
  - The first USB probided Android debug bridge, the second provided serial connection to DUT

Test Software

- Two primary test software types were uses
  - First: Performs entire SEE test before OS starts – renders it unable to perform I/O until later Second: Performs SEE test after OS brings up I/;O system and provides immediate info about SEE

Snapdragon 820 SEE Test Plan

Annealing

- Stuck bits were making it impossible for devices to boot and run test software after relatively limited exposures
- Rotation was established where at least one test board was always being annealed while another was being irradiated
- DUT boards removed from neutron beam were activated and could not always be safely handled

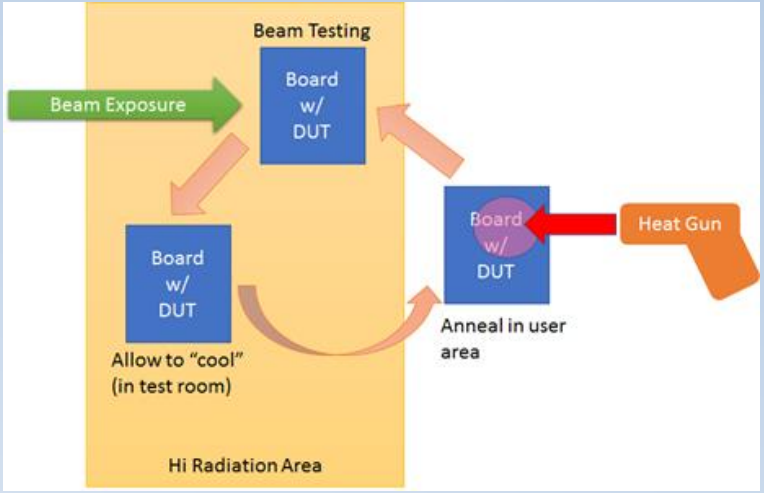
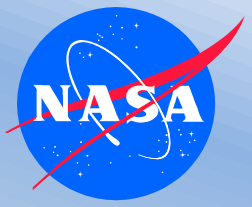


Figure 3: Rotation of test boards during stuck bit accumulation (beam exposure) and annealing.



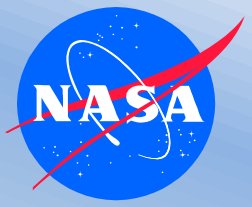
Snapdragon 820 SEE Results

Proton and Neutron Results

- 23 crashes were observed across three proton energies
- SBUs were observed in the DDR4 device and was similar to the number of stuck bits
- Stuck bits were observed during booting and testing
  - Stuck bits would create situation where the test board was no longer functional (especially during neutron testing). Solution was to anneal

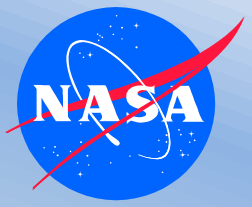
Heavy Ion Results

- Not a significant amount of displacement damage, leaving ionization to impact processor and cause crashes more so than stuck bits in DDR4
- Using test code injected in Android boot loader was tested for register bit errors
  - 20 registers tested each containing 64 bits and with no bit errors
- SEL not observed (only secondary goal here)



Snapdragon SEE Test Conclusion - I

- Crashes were the dominant error type observed in proton, neutron, and heavy ion testing
  - The nature of crashes between heavy ion, neutron, and proton exposures is similar
- Stuck bits were limited to proton and neutron testing
  - DDR4 devices were expected to have similar sensitivity to bit upsets and stuck bits
- POP structure required all test beams to transverse the DDR4 device
  - This contributed to a large number of stuck bits and memory bit errors



Snapdragon SEE Test Conclusion - II

- Package-on-Package is a version of the SOC problem that impacts complex devices
  - Removing POP stacks is only a stop-gap
- Stuck bits, and other micro-dose or dose-related damage will impact future SEE tests
- Ability to anneal dose / recover radiation damage will improve tests of complex systems
- DDR4 SEEs and stucks create a background “noise” rate that is indicative of complex systems