Testing the Tester: Lessons Learned During the Testing of a State-of-the-Art Commercial 14nm Processor Under Proton Irradiation

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To be presented by Carl M. Szabo, Jr., at the RADECS 2017 Radiation Effects on Components and Systems (RADECS) Conference, Geneva, Switzerland, October 3, 2017.

Acronyms

- Basic Input/Output System (BIOS)
- Device Under Test (DUT)
- Graphical Processing Unit (GPU)
- Goddard Space Flight Center (GSFC)
- High Definition Multimedia Interface (HDMI)
- Massachusetts General Hospital (MGH)
- National Aeronautics and Space Administration (NASA)
- NASA Electronic Parts and Packaging (NEPP) Program
- Random Access Memory (RAM)
- Solid State Disk (SSD)
- single event effect (SEE)
- Thermal Design Power (TDP)
- Universal Serial Bus (USB)

Background

Circa 1986, playing with an Atari 1040ST

- **Lifelong Computer Hobbyist and Enthusiast**
  - **Unconventional Training and Skill Set**
- **System Administrator supporting GSFC since 2002**
  - **Duties often require flexibility and out of the box thinking to solve unplanned problems / handle unexpected events**
- **Introduced to Radiation Effects ~2012**
  - **“Person Under Test”**

Device Under Test

- **Intel core i5-6600K “Skylake” Microprocessor**
  - **ASUS Z170M-Plus Motherboard, 8GB RAM, 750W Power Supply, SSD, USB and HDMI over Ethernet control**
  - **Microsoft Windows Server 2012R2 OS, HWiNFO System Monitoring, Linpack, FurMark, Prime95 Stress, Batch File Control**
  - **In-situ, “System Level” Best Effort Approach**
- **Proton Testing via**
  - **TRIUMF 105 MeV Beam Line (November 2015)**
  - **MGH 200 MeV Beam Line (October 2016)**

What Happened

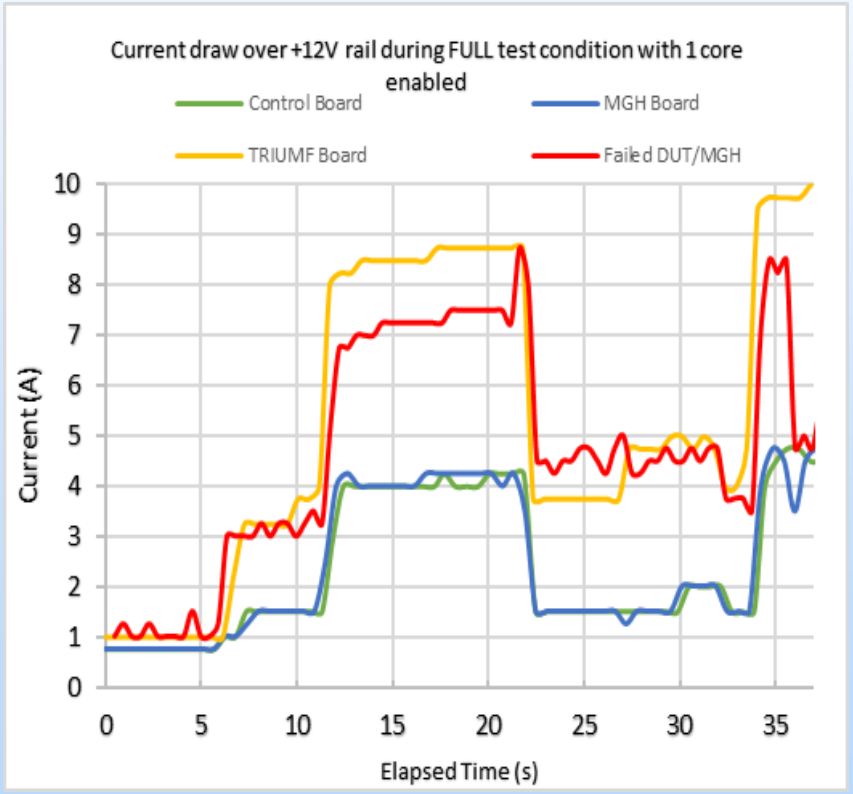
- **Hard failure event observed during TRIUMF visit**
  - **Device appeared to lose integrated GPU functionality during irradiation**
    - **Failure occurred during “Full” test (Linpack + FurMark) with only 1 CPU core active**
  - **Results were difficult to explain at the time of testing**
- **Subsequent testing at MGH yielded no functional failures after 60+ test runs!**
  - **How??**
- **Next day at MGH, re-tested board used during TRIUMF tests**
    - **Processors began to fail!**

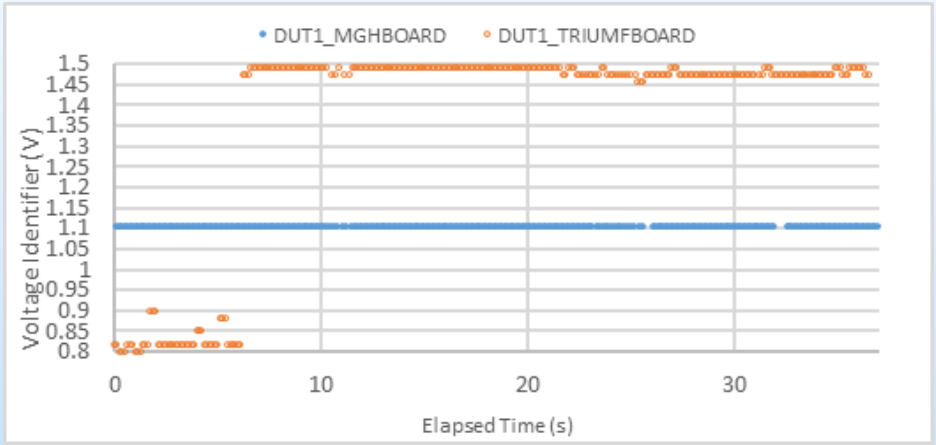
Troubleshooting 1/3

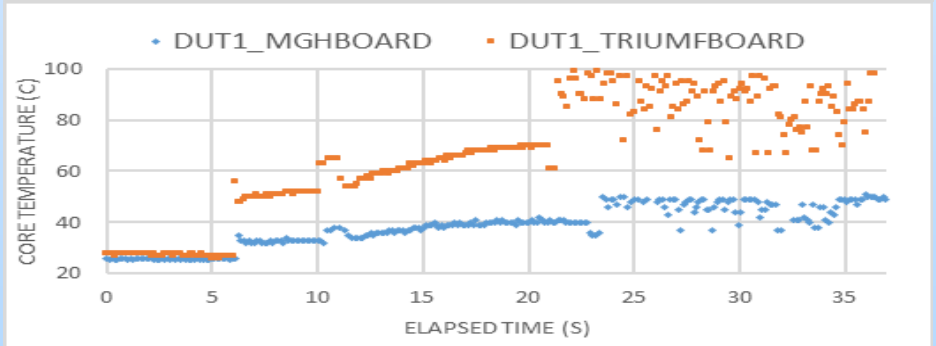
- Product was new and period of testing was short
  - First setup featured early release hardware
  - Public discovers flaws (Prime95 lockup issue)
- Test setup evolved as the device technology matured
  - Later procured motherboards featured updates
    - BIOS revision of board used at MGH operated DUT differently than board and BIOS version used at TRIUMF
  - Supporting hardware and software enabled enhanced data collection
    - Accurate data
  - Evolution of test setup allowed insight that was not possible in early testing
  - Retesting on the MGH and TRIUMF-tested boards showed same behaviors with fresh processors

Troubleshooting 2/3

- **Large differences in functional parameters**
  - **Failures only occurred during exposure to protons**
  - **These differences would likely be transparent to regular users**







Troubleshooting 3/3

- **Motherboard used at TRIUMF operated DUT in excess of rated 91 Watt TDP!**
  - **Only 1 processing core active**
  - **Degradation of performance after 18 hour extreme stress test**
    - **Failed Linpack tests**
    - **Could not reproduce GPU functional failure**
- **Motherboard used at MGH operated DUT more efficiently**
  - **Lower temperature operation**
  - **Fewer changes in voltage**
  - **Slightly better performance**
- **Control Motherboard (latest BIOS available as of Sep. 2017)**
  - **Behavior largely the same as MGH motherboard**

Conclusion

- Early hardware and software is imperfect
  - Perform updates BIOS, microcode, hardware and software
- Up-to-date hardware and software leads to
  - Increased data
  - Accurate data
    - Correctable / Uncorrectable Error Reporting
- However, current product cycle is changing quickly
  - How feasible to characterize?
    - Limited time begets limited reliability data
  - Flight project cannot tolerate lack of supply + reliability data, nor frequent updates