Proton Testing of nVidia GTX 1050 GPU, Part 2

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1. Acronyms

BGA	Ball Grid Array
BSOD	Blue Screen of Death (Windows crash message)
Cat5e	Category 5e (enhanced) specification
COTS	Commercial Off the Shelf
CPU	Central Processing Unit
CUDA	Compute Unified Device Architecture
CUFFT	CUDA Fast Fourier Transform library
DHCP	Dynamic Host Configuration Protocol
DRAM	Dynamic random-access memory
DUT	Device Under Test
EGL	Embedded-System Graphics Library
ES	Embedded Systems
GPU	Graphical Processing Unit
GUI	Graphical User Interface
HDMI	High-Definition Multimedia Interface
IPv6	Internet Protocol version
MGH	Massachusetts General Hospital
OpenGL	Open Graphics Library
OpenCL	Open Computing Language
RAM	Random Access Memory
RJ45	Registered Jack #45
SDK	Software Development Kit
SEE	Single Event Effects
SEFI	Single Event Functional Interrupt
SKU	Stock Keeping Unit
SNTP	Simple Network Time Protocol
SOC	System on Chip
SOM	System on Module
SRAM	Static Random Access Memory

2. Introduction and Summary of Test Results

Single-Event Effects (SEE) testing was conducted on the nVidia GTX 1050 Graphics Processor Unit (GPU); herein referred to as device under test (DUT). Testing was conducted at Massachusetts General Hospital's (MGH) Francis H. Burr Proton Therapy Center on April 28th, 2018 using 200-MeV protons. This testing trip was purposed to provide additional radiation susceptibility data from payloads compiled in Q3FY18. While not all radiation-induced errors are critical, the effects on the application need to be considered. More so, failure of the device and an inability to reset itself should be considered detrimental to the application. Radiation effects on electronic components are a significant reliability issue for systems intended for space.

The testing that has been conducted covered three types of test vectors: OpenCL, OpenCL with Mutex and OpenGL. Except in the case of a single event functional interrupt (SEFI), the test vectors employed in this round of testing were created to target the shared memory, texture memory and control logic of the DUT. Because the device was recoverable upon a power cycle of the computer system (CPU, mainboard and GPU), its use in a radiative environment may be possible given a hardware or software watchdog routine to detect an error and reset the device.

3. Device Tested

The nVidia GTX 1050 GPU is a graphic coprocessor for use in a modern COTS computer. The carrier board is connected to the computer motherboard via a PCI-e x16 slot. The GPU die, itself, is the device under test (DUT) and is located underneath the unit's heat sink. Figure 1 shows pictures of the heat sink and graphics card. Table 1 gives information on this part.

Figure 1: Nvidia GTX 1050 GPU with Heatsink (left) and As-Tested (right)

Table 1: Part Identification Information

Quantity	1
Part Model	GTX 1050
Board Model	EVGA 02G-P4-6152-KR
REAG ID	17-039
Manufacturer	nVidia
Technology	14nm CMOS
Packaging	Flip Chip, BGA

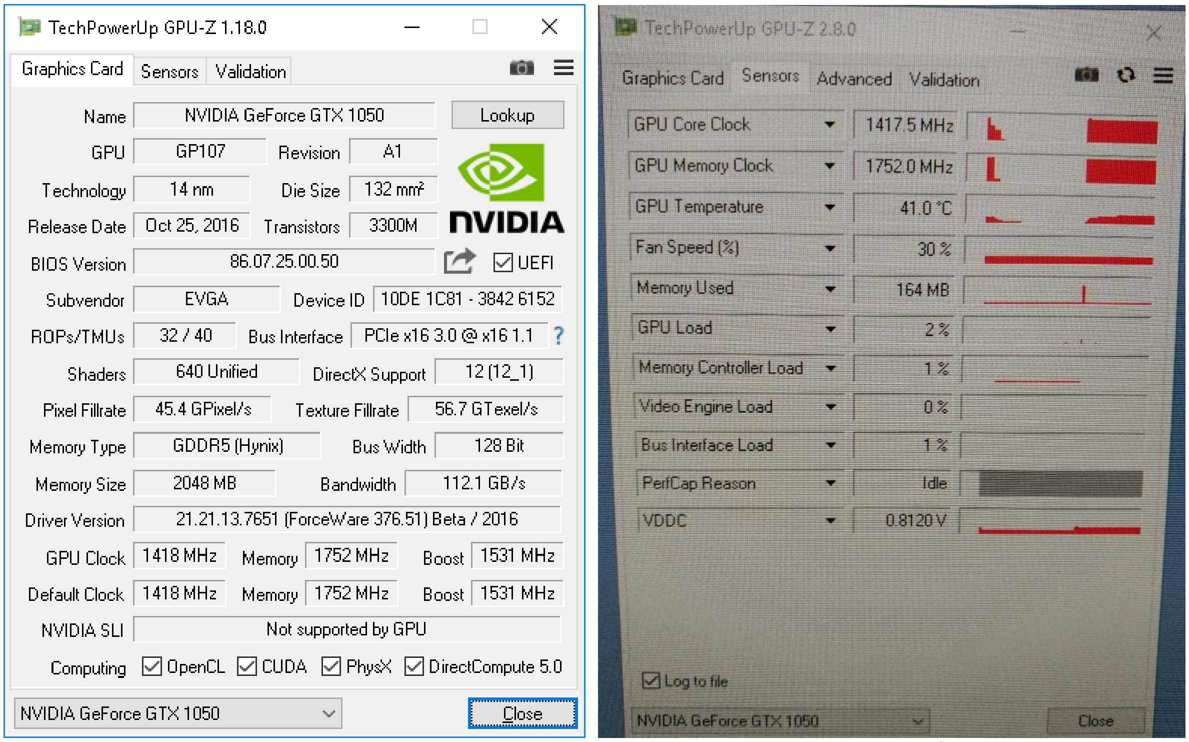

Figure 2: Nvidia GTX 1050 GPU - Device Parameters as Shown in GPU-Z[1]

4. Test Facility

Facility:	Massachusetts General Hospital's (MGH) Francis H. Burr Proton Therapy Center
Ion species:	Proton
Energy:	200 MeV

5. Test Setup

The DUT relies on a typical computer setup in order to be used. Here, the following platform bill of materials (BOM) was utilized (Table 2) along with Newegg part numbers. The operating system was Windows Server 2016.

A custom tooled cooling solution was created to permit beam access to the DUT die from the obverse side while absorbing the heat through the reverse side of the printed circuit board. This orientation permitted nominal operation from both the DUT GPU and a control GPU (with stock cooling solution) within the test bench. The cooling solution allows the device to operate under load while maintaining an ambient temperature appropriate for the test (i.e. 20°C). While not defined in Table 2, the cooling system uses 400W of thermoelectric coolers, a large aluminum fan sink and a secondary ambient blower.

[1] https://www.techpowerup.com/gpuz/

Table 2: Computer Platform - Bill of Materials

Newegg.com Part #	Description
N82E16813132573	ASUS Z170M-PLUS LGA 1151 Intel Z170 HDMI SATA 6Gb/s USB 3.0 Micro ATX Intel Motherboard
N82E16819117561	Intel Core i5-6600K 6M Skylake Quad-Core 3.5 GHz LGA 1151 91W BX80662I56600K Desktop Processor Intel HD Graphics 530
N82E16814487296	EVGA GeForce GTX 1050 SC GAMING, 02G-P4-6152-KR, 2GB GDDR5, DX12 OSD Support (PXOC)
N82E16820233831	CORSAIR Vengeance LPX 16GB (2 x 8GB) 288-Pin DDR4 SDRAM DDR4 2133 (PC4 17000) Desktop Memory Model CMK16GX4M2A2133C13
N82E16817139142	CORSAIR RMx Series RM750X 750W 80 PLUS GOLD Haswell Ready Full Modular ATX12V & EPS12V SLI and Crossfire Ready Power Supply
N82E16820236156	Corsair Force MP500 M.2 2280 120GB PCI-Express 3.0 x4 Internal Solid State Drive (SSD) CSSD-F120GBMP500

An external arbitration computer (laptop) operating over a closed network was used to interrogate the device, execute remote commands and monitor the DUT health. A second laptop was used as “eyes-in-the-room” to view a monitor connected to the DUT which was located in the beam room. This was done via two different methods:

- IP camera on closed network aimed at the monitor
- HDMI capture device with video stream recorded using VLC player

A. Arbiter Setup

Network-based remote HDMI and USB hardware (Startech IPUSB2HD3), and a network based IP camera (Foscam FI9900P) were used to remotely control and view the DUT computer platform. A video capture device (StarTech USB3HDCAP) was used to record a video stream from the DUT over USB 3.0. This redundant-monitoring approach permitted direct control of the DUT during the test and minimized the risk of false errors recorded due to upsets in the primary networking connection itself.

Payload software was placed on an FTP storage site local to the closed network’s router (TP-LINK TL-WR1043ND) for easy update, download and results extraction between DUT and arbitrator. Video recordings from the OpenGL tests were saved locally due to their large file size (~10GB per video).

B. Test Vector Software

The following test payloads were performed using payload code developed at GSFC.

- Shared memory and Control logic v1
- Shared memory and Control logic v2 (includes Mutex)
- Graphics & texture Memory

C. Hardware

The DUT is the graphics chip located on the PCI-e carrier board. Due to the orientation of the GPU on the system board, a riser cable (Digikey part number 3M12026-ND) was used to place the GPU above the test computer. This also permitted the computer to be surrounded by lead and Lucite bricks to prevent SEFIs on the motherboard. The beam was aligned to the obverse side of the GPU card. No fan-sink is located on this side of the card because sufficient cooling is produced on the reverse side of the card from the cooling system. There was sufficient clearance around the GPU chip and no components were present on the secondary side of the system board within the z-axis of the chip. This was advantageous as it allowed some radiation shielding to other system components such as the power management and flash memory components.

Lucite bricks were used to shield the power supply of the DUT from scattered neutrons which are a result of proton collisions within materials in the beam's path. A photograph of the board under test is shown in figure 3. Scissor-stands and vices were used to hold the cooling system and the secondary ambient blower (8" duct fan).

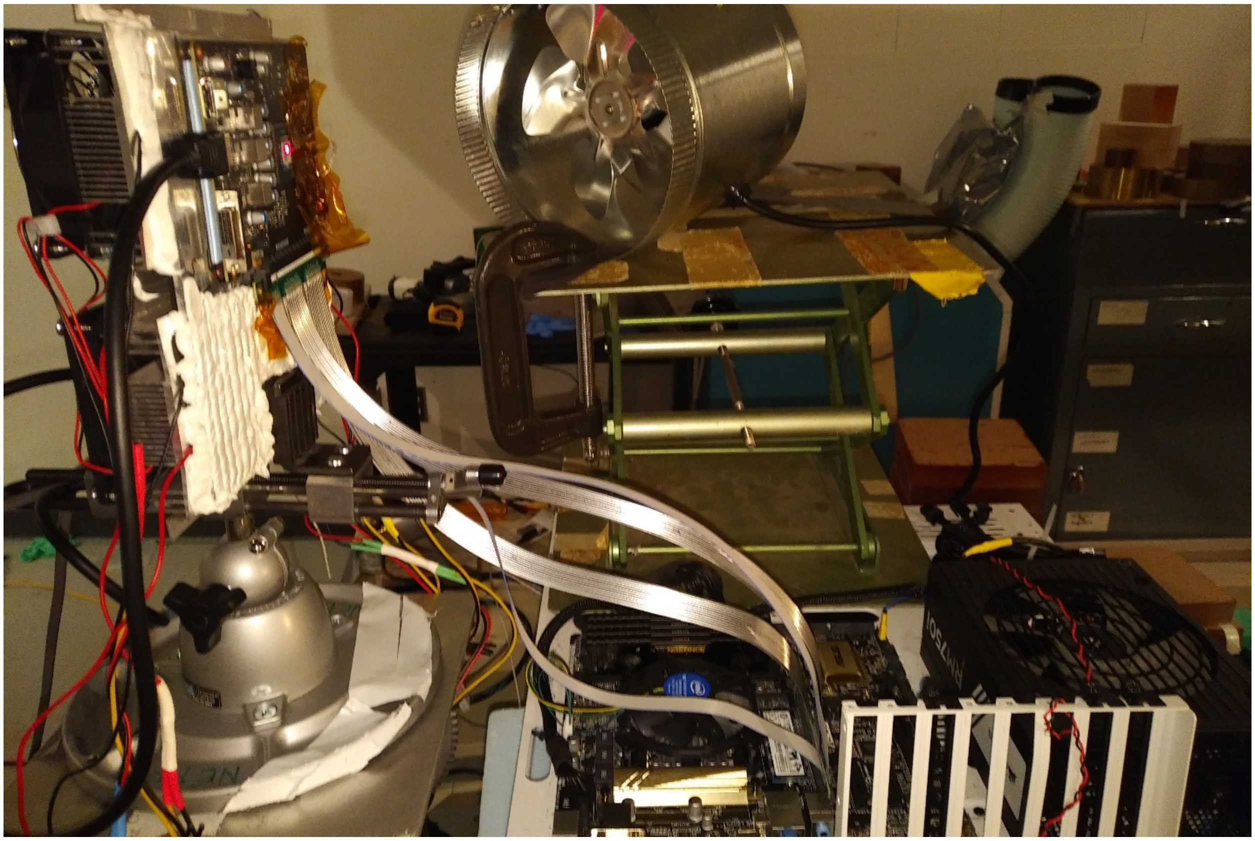

Figure 3: nVidia GTX 1050 GPU in laser alignment beam at MGH

6. Test Procedure and Results

Eighteen (18) runs were performed. The occurrence and types of upset events are shown in Table 3. In Figure 4 a screen shot shows the visual record of each type (where applicable). Any network loss was investigated using the IP Camera, and networking at the router and arbiter.

Table 3: Upset Type Occurrence

Event	**Occurrence**
System Halt, Power Reset (SEFI)	17
Pixel Artifacts	7
DUT unresponsive at test initiation (after forced restart)	5
System OK, DUT halted	3

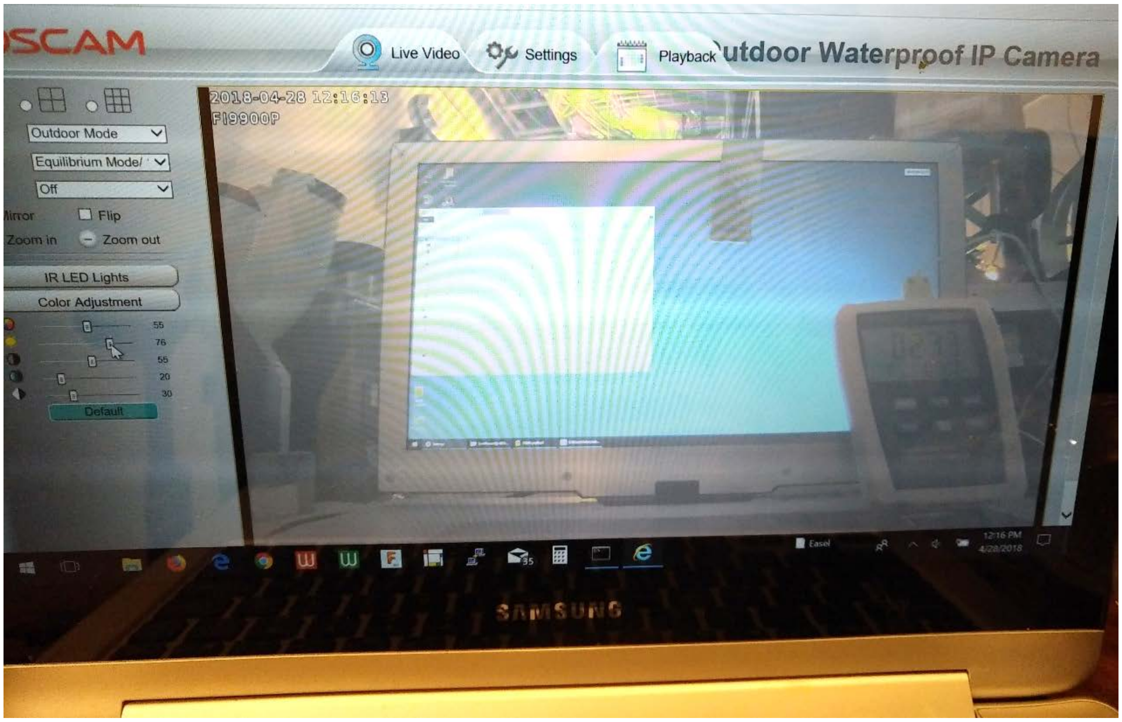

Figure 4: "Eyes in the Room" View of In-Room Monitor and Thermocouple Datalogger during Irradiation

A tabulation of the crash conditions and beam parameters is provided in Table 4.

It is also worth noting that upon power cycling the device, the device behaved normally. Further, no drift in temperature was noted other than a negligible increase due to computational loading. This was correlated between software sensors in GPU-Z (as seen in Figure 2) and a thermocouple placed on the DUT's die fillet.

Figure 5 shows the results of the proton testing with SEU cross section and SEFI cross section.

Table 4: Testing Results

Run#	DUT	Test Mode	Flux	Effective Fluence	Dose rad (Si)	SEU Cross section	SEFI Cross section	Minimal # Upsets	SEFI Condition	DUT Unresp. Condition	System OK, DUT Halt Condition	Pixel Artifacts Condition
1	1	MATH_V1	5.93E+08	9.95E+09	578.10	1.00E-10	1.00E-10	1	1			
2	1	MATH_V1	2.72E+08	1.83E+10	1061.90	5.47E-11	5.47E-11	1	1			
3	1	MATH_V1	2.46E+08	1.62E+09	94.30	6.16E-10	6.16E-10	1	1			
4	1	MATH_V1	2.84E+08	2.74E+10	1590.80	3.65E-11	3.65E-11	1	1			1
5	1	MATH_V1	2.29E+08	7.98E+09	463.30	1.25E-10	1.25E-10	1	1	1		
6	1	MATH_V2	3.14E+08	2.82E+09	164.00	3.54E-10	3.54E-10	1	1	1		
7	1	MATH_V2	2.60E+08	2.97E+09	172.20	3.37E-10	3.37E-10	1	1			
8	1	MATH_V2	2.45E+08	2.65E+10	1537.50	3.78E-11	3.78E-11	1	1	1		
9	1	MATH_V2	2.94E+08	1.31E+10	758.50	7.66E-11	7.66E-11	1	1			
10	1	MATH_V2	3.05E+08	2.17E+10	1262.80	4.60E-11	4.60E-11	1	1		1	
11	1	OGL	2.90E+08	1.12E+10	647.80	8.96E-11	8.96E-11	1	1			1
12	1	OGL	2.91E+08	8.54E+09	496.10	1.17E-10	1.17E-10	1	1	1		1
13	1	OGL	3.04E+08	4.17E+10	2423.10	2.40E-11	2.40E-11	1	1		1	1
14	1	OGL	2.98E+08	1.57E+10	914.30	6.35E-11		1			1	1
15	1	OGL	3.00E+08	2.05E+10	1193.10	4.87E-11	4.87E-11	1	1	1		1
16	2	MATH_V1_2ndGPU	3.03E+08	1.11E+10	643.70	9.02E-11	9.02E-11	1	1			
17	2	MATH_V2_2ndGPU	3.16E+08	1.67E+10	967.60	6.00E-11	6.00E-11	1	1			
18	2	OGL_2ndGPU	3.22E+08	5.22E+09	303.40	1.91E-10	1.91E-10	1	1			1

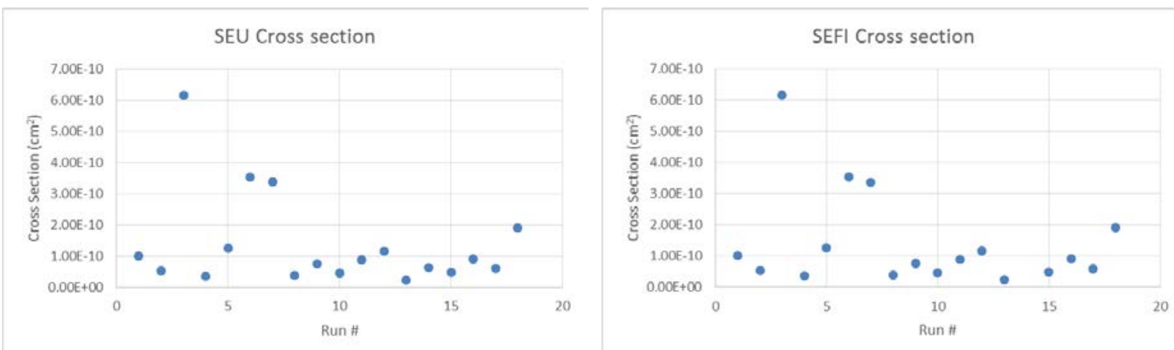

Figure 5: Cross Section Results from Test Runs