Proton Testing of nVidia GTX 1050 GPU

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1. Acronyms

BGA	Ball Grid Array
BSOD	Blue Screen of Death (Windows crash message)
Cat5e	Category 5e (enhanced) specification
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
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 9th, 2017 using 200-MeV protons. This testing trip was purposed to provide a baseline assessment of the radiation susceptibility of the DUT as no previous testing had been conducted on this component. 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 should be considered a very partial test vector. One of the primary goals of this test was to prove out new arbitration capabilities used to monitor the DUT during testing. Because the DUT is a coprocessor, it is necessary to modify a commercial off the shelf (COTS) computer to perform the testing. Except in the case of a single event functional interrupt (SEFI), the test vectors employed in this round of testing were created to target one type of memory structure within the DUT (e.g. L1, L2, shared, registers) and the control logic itself. 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 PCIe x16 slot. The GPU die, itself, is the device under test (DUT) and is located underneath the unit's heat sink.

Figure 1: Nvidia GTX 1050 GPU

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

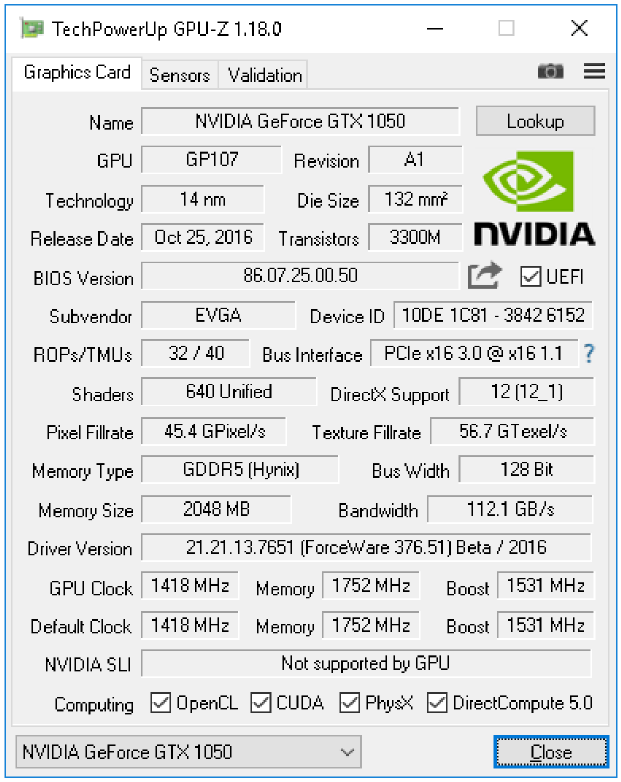

Figure 2: Nvidia GTX 1050 GPU - Device Parameters

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 numbersThe operating system was Windows Server 2016.

Table 2: 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 is 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.

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. 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.

Power supply measurements were conducted using a laptop connected to a Corsair RM750i power supply with an embedded OEM-supplied monitoring solution. The software, HWInfo (hwinfo.com), was used to save the real time log files from the power supply unit.

B. Test Vector Software

The following test payloads were performed. The code source is noted for each one.

- L1 (NSWC)
- Shared (NSWC)
- Control logic, Dynamic (GSFC)
- Graphics & texture Memory (Furmark[1])

[1] http://www.ozone3d.net/benchmarks/fur/

C. Hardware

The DUT is the graphics chip located on the PCIe 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 backside of the GPU card. A fan-sink is located on the component side of the card. 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 the figure. A tripod mountable computer case was used to mount the computer vertically.

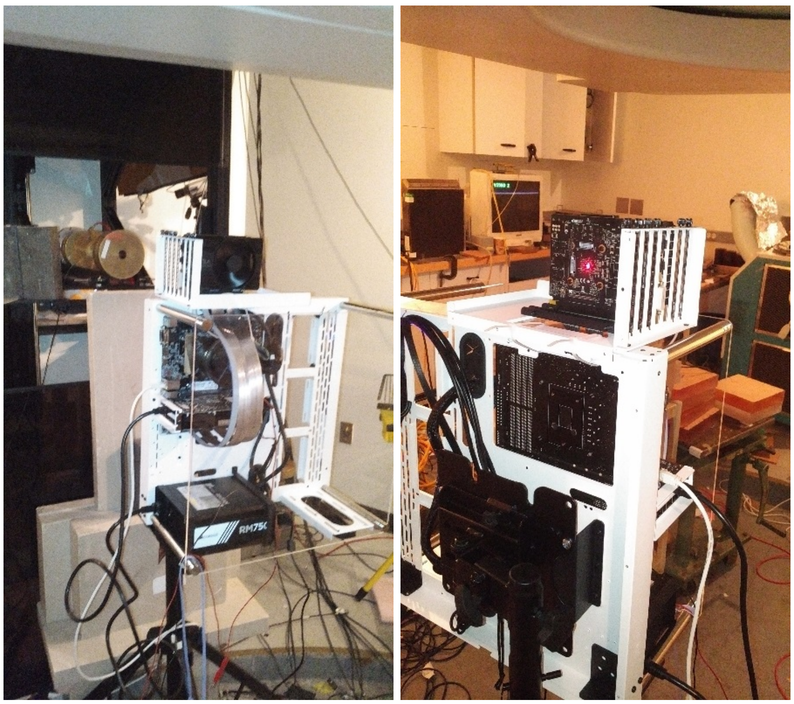

Figure 3: nVidia GTX 1050 GPU in laser alignment beam at MGH

6. Test Procedure and Results

Thirty (30) runs were performed. The occurrence and types of upset events are tabulated below. A screen shot is provided to show 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	13
Pixel Artifacts	6
DUT unresponsive at test initiation	2
No noticeable events or system latency noticeable	9

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.

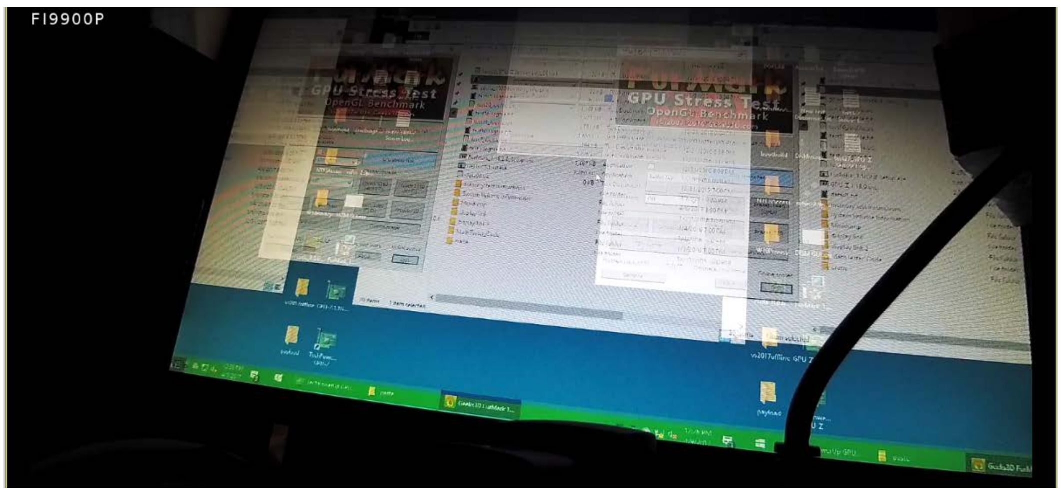

Figure 4: "Eyes in the Room" View of Graphics Artifacts during Irradiation

Table 4: Testing Results

Run#	Test Mode	flux	Effective Fluence	Dose rad (Si)	#SEFI	upsets	Crash Condition
1	Dynamic	2.93E+08	1.00E+10	581.68			
2	L1	2.88E+08	1.00E+10	581.68	1		BSOD
3	Shared	2.88E+08	1.00E+10	581.68		1	pixel
4	Shared	2.83E+08	1.00E+10	581.68	1		BSOD
5	Dynamic	2.88E+08	1.00E+10	581.68			
6	L1	3.00E+08	1.37E+10	793.20		1	
7	Shared	3.04E+08	1.37E+10	793.20	1		BSOD
8	Dynamic	3.06E+08	1.71E+10	991.50			
9	L1	3.03E+08	1.71E+10	991.50		1	
10	Shared	3.00E+08	1.71E+10	991.50		1	
11	Dynamic	2.88E+08	2.28E+10	1322.00			
12	L1	2.88E+08	2.28E+10	1322.00		1	BSOD
13	Shared	2.97E+08	2.28E+10	1322.00	1		BSOD
14	Dynamic	3.03E+08	2.71E+10	1573.18	1		BSOD
15	L1	2.97E+08	2.85E+10	1652.50	1		BSOD
16	Shared	2.93E+08	2.85E+10	1652.50	1		BSOD
17	Dynamic	3.01E+08	2.22E+10	1288.95	1		BSOD
18	Dynamic	3.03E+08	7.64E+09	442.87	1		BSOD
19	Dynamic	3.13E+08	3.42E+10	1983.00			
20	L1	3.04E+08	9.12E+09	528.80	1		BSOD
21	Shared	2.97E+08	3.42E+10	1983.00	1		BSOD
22	L1 In-situ	2.59E+08	9.80E+09	568.46			DOA
23	L1 In-situ	2.30E+08	5.24E+09	304.06	1		BSOD
24	Furmark	2.61E+08	1.00E+10	581.68		1	pixel
25	Furmark	2.53E+08	7.30E+09	423.04		1	pixel
26	Furmark	3.08E+08	1.37E+10	793.20		1	pixel
27	Idle	2.87E+08	8.44E+09	489.14		1	
28	Shared	2.75E+08	9.58E+09	555.24	1		pixel
29	L1	2.59E+08	1.37E+10	793.20	1		pixel
30	Furmark	n/a	n/a	n/a			DOA