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Single-Event Effects Test Report #2 Texas Instruments TDA4VM System on Chip

Edward J. Wyrwas
Columbus Technologies and Services, Inc., Greenbelt, MD 20770

Testing Date: August 28, 2025
Test Report Completed: September 17, 2025

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

October 2025

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1. Introduction and Purpose

This report discusses the failure modes and heavy ion radiation sensitivity of the Texas Instruments Jacinto TDA4VM system on chip (SoC). The device was monitored for destructive events, unexpected current draw, and graphical display errors during exposure to a heavy ion beam at Lawrence Berkeley National Laboratory (LBNL)'s 88-inch cyclotron.

The purpose of the test was to evaluate whether the larger overhead resources associated with the Vulkan Graphics framework, as compared to OpenGL, will produce a worse radiation cross section. The data obtained in this test was compared to and combined with [1]. It was previously determined that the TI AD4VM could be used for a variety of human-centric flight systems such as a display on a space suit or exploration vehicle with human-machine interfaces (HMI) that contain displays.

2. Test Result Summary

The TI TDA4VM system on chip experienced a destructive event at a LET of ~68 MeV/(mg/cm^2) which impacted the USB bus on the SOC (behavior shown in Figure 13). While some system instability and single event functional interrupts were noted, the device operated nominally throughout most of the testing. This result differs from the previous testing campaign and is due to the higher LET. The failure occurred during an IDLE test run with no test routine other than having the OS loaded to stress the DUT. The premise that a graphics-based test will have a lower cross section than an idle test held true while below 55 MeV/(mg/cm^2). At this LET, SEFIs and extreme current draw when the beam was initiated dominated the test behavior.

3. Device Description

The device is a 16-nm FinFET System on Chip (SoC) with an ARM core complex containing two Cortex A72, six Cortex R5F, an 8-TOPS Ai accelerator and two DSP cores. The BeagleBone AI-64 (BBAI-64) single board computer (Figure 1), which acts as the test vehicle, has 4GB RAM, 16GB of flash storage, three USB 3.0 ports, an M.2 E-Key socket with PCIe, USB and SDIO, plus expansion headers providing GPIO, PWM and ADC capabilities. The device also contains a low power embedded Imagination® PowerVR® Rogue 8XE GE8430 GPU (up to 750MHz, 96GFLOPS, 6Gpix/sec) with a mini-DisplayPort display connector. The GPU is the primary point of study for this test campaign.

[1] Single-Event Effects Test Report Texas Instruments TDA4VM System on Chip. https://ntrs.nasa.gov/citations/20250002872

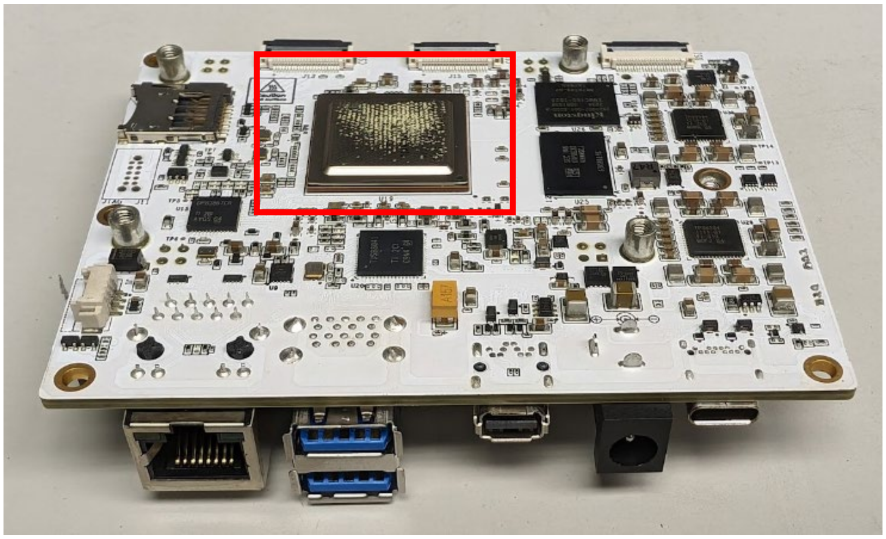


Figure 1: Photograph of BBAI-64 Single Board Computer with TI TDA4VM processor (marked)

The TI device, while low power, is capable of driving HD displays, performing H.264/H.265 encoding, inferring upon Ai models using common frameworks, and rendering 3D graphics using OpenGL and modern graphics engines (i.e., Vulkan).

It is automotive grade targeting Functional Safety-Compliance with a level of ASIL-D. The device can be procured as AEC-Q100 qualification. The device also contains embedded hardware security modules and cryptography accelerators. The memory subsystem[2] is as follows:

- Up to 8MB of on-chip L3 RAM with ECC and coherency
  - ECC error protection
  - Shared coherent cache
  - Supports internal DMA engine
- External Memory Interface (EMIF) module with ECC
  - Supports LPDDR4 memory types
  - Supports speeds up to 4266MT/s
  - 32-bit data bus with inline ECC
- General-Purpose Memory Controller (GPMC)
- 512KB on-chip SRAM in MAIN domain, protected by ECC

This device can be procured as a piece-part (24 mm × 24 mm, 0.8-mm pitch, 827-pin FCBGA, enables IPC class 3 PCB routing) or as a system-on-module permitting system designers great flexibility when it comes to system design complexity and ease of integration.

[2] Datasheet for Texas Instruments TDA4VM Processors

Table 1: Test and Part Information

Generic Part Number	TDA4VM
REAG ID	24-009
Manufacturer	Texas Instruments
Lot/Date Code	N/A, Procurement Q1 2024
Quantity Tested	1
Part Function	System on Chip
Package Style	24 mm × 24 mm, 0.8-mm pitch, 827-pin FCBGA
Test Engineer	Edward Wyrwas
Test Equipment	NEPP GPU Test Bench

4. Test Setup

To prepare the device for test, the TI TDA4VM was thinned to approximately 100 microns by Sage Analytical Labs. An image of the pre-thinned die and depth map taken by Sage Analytical can be seen in Figure 2 and Figure 3, respectively. The same device from the prior test was utilized in this study.

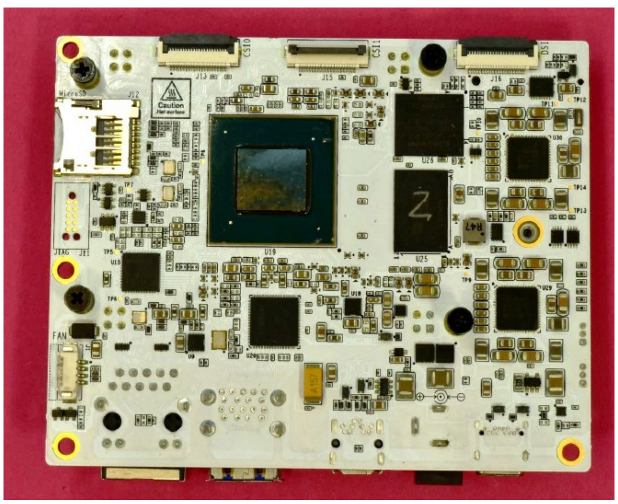


Figure 2: Photograph of Thinned TI TDA4VM Die

Figure 3: Pre-thinned TI TDA4VM die depth map measured by Sage Analytical

5. Test Facility

This heavy ion test was performed at Lawrence Berkeley Nations Laboratory's 88-inch cyclotron. The beam tune used in the test was the 20 MeV/amu tune. The ions used in this study and the total approximate range for each is shown in Table 2.

Table 2: 20MeV/amu Ions Used in this Study

20MeV/amu Order	Ion	Symbol	Approx. LET ($MeVcm^2/mg$)	Ion Range (um)	Total Range (cm)
1	Oxygen	O	1.2	700	1.007
2	Vanadium	V	13	230	1.023
3	Silver	Ag	55	120	1.012
4	Xenon	Xe	68	105	1.010

6. Test Conditions

The test was performed in-air, at an approximate distance of 1cm away from the beam's exit from its vacuum. The device was mounted at an incidence angle of 0° between the beam path and device. The device was operated nominally using a 5V 4-amp power supply. The spot size was $1cm^2$. Forced air (dry N_2) cooling was employed during the test to assure the device stayed within nominal operational conditions without a heat sink directly on top of the SoC.

7. Test Methods and Procedures

The test bench for this device is the evolution of [3, 4, 5] which permits NASA to explore more than the memory cache architecture of the device. Prior testing performed by the Aerospace Corporation [6] showed that the device was capable of performing Ai workflows and running Ai models during irradiation. Ai models were not included in the test suite for this work to best optimize the use of beam time at the facility.

The test suite operations utilized in this work consisted of the following list. The same Operating System (OS) utilized in the previous test campaign, utilizing different conditions of "Idle state" to determine if lack of a constant cache eviction routine (whether trivial or prognostics) will induce a higher cross section than running a complex operation such as a graphics intensive flight-like application like STAR[7].

- Debian 12.7 OS configured with Xfce desktop environment
- SSH remote terminal over LAN networking
- Vulkan Application Rendering (STAR) with real time screen capture

A replacement top side heatsink was fabricated with a window to expose the device to the beam while providing heat sinking around its perimeter. A thermal interface material was used to both assure active

[3] Considerations for GPU SEE Testing. E. Wyrwas. NASA 2017. https://ntrs.nasa.gov/citations/20170004734
[4] Standardizing Microprocessor and GPU Radiation Test Approaches. E. Wyrwas. NASA 2019. https://ntrs.nasa.gov/api/citations/20190028690/downloads/20190028690.pdf
[5] AMD Radeon e9173 Low Power PCIE GPU Single Event Effects Test Report. E. Wyrwas. NASA 2023. https://ntrs.nasa.gov/citations/20230009291
[6] Proton Testing of Texas Instruments TDA4VM SoC. S. Davis. IEEE NSREC 2024. https://ieeexplore.ieee.org/document/10759193
[7] Trades, Architecture, and Design of the Joint Augmented Reality Visual Informatics System (Joint AR) Product, slide 17: STAR (Space Technology Application Renderer) Graphics Engine https://ntrs.nasa.gov/citations/20230009093

components could maintain vertical contact to the heatsink and also act as a shield for the micro-SD Card against scattered particles. A photograph of the mounted device can be seen in Figure 4.

The device was operated nominally using a 5V 4-amp power supply which was controlled through a relay-driven power switch in the operator room. The other equipment in the cave was connected to a network-controlled power switch for remote operation and troubleshooting to minimize downtime. The voltage, current and power was monitored in-situ using a microcontroller with sensors for the same. This monitoring system also provided in-cave environmental readings of humidity, temperature, and atmospheric pressure. This monitoring system was connected to the Wireless network in the cave.

This device monitoring system also provided a rigid mounting point for the BBAI-64 through a set of stacked headers on its GPIO. A 3D printed fixture was created to mount this PCBA to the motion control system in the cave for consistent placement of the device if more than one device was to be tested (in case of destructive failure).

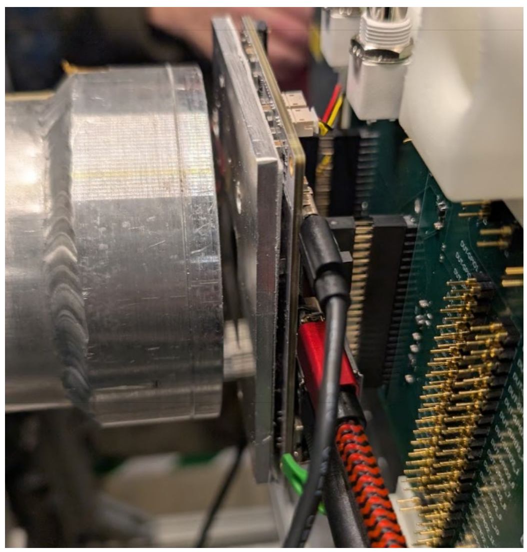


Figure 4: Photograph of BBAI-64 PCBA Mounting

The monitoring data was recorded to a time-series database called InfluxDB[8] and monitored using a Grafana[9] dashboard as it was in the previous test. A notional diagram of the test bench is shown in Figure 5 and Figure 6.

[8] https://www.influxdata.com/
[9] https://grafana.com/

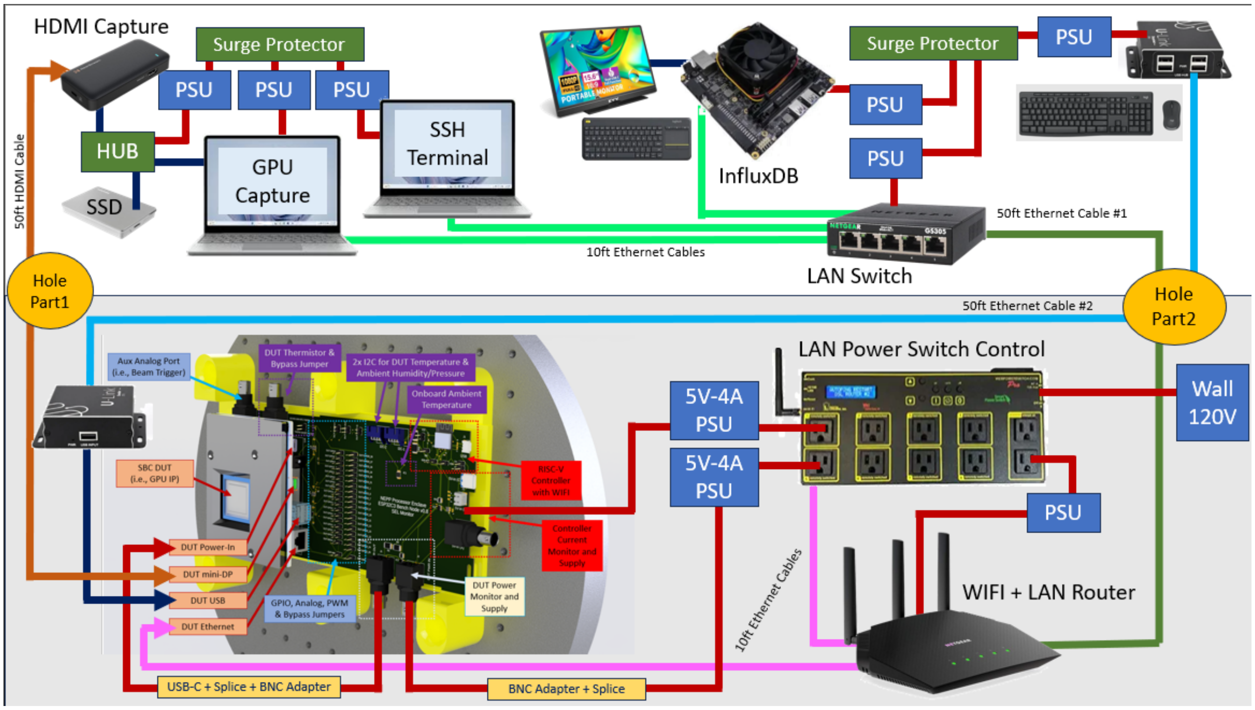


Figure 5: Diagram of Test Bench Configuration

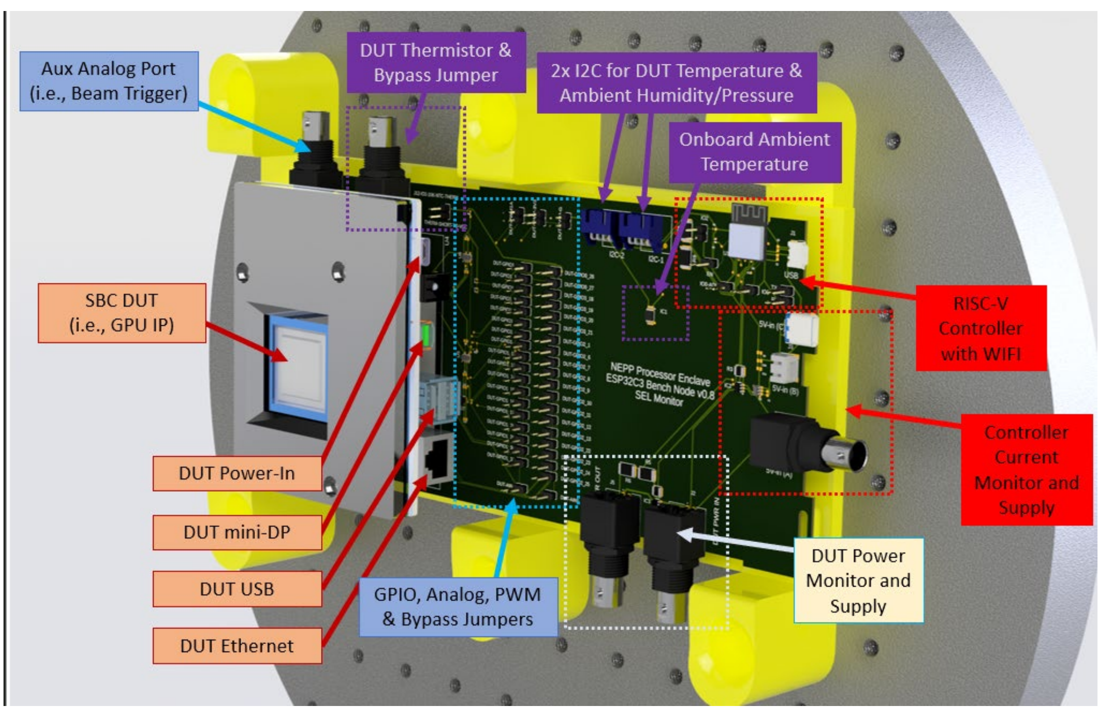


Figure 6: Diagram of BBAI-64 Mounting Configuration

The graphics display was recorded and saved to file for post processing of individual frames to identify erroneous operation versus a golden sampling of the STAR application. An exemplar screenshot from the previous test showing the recording of a GPU rendering test, test script operation and environmental monitoring as seen during the test is provided in Figure 7.

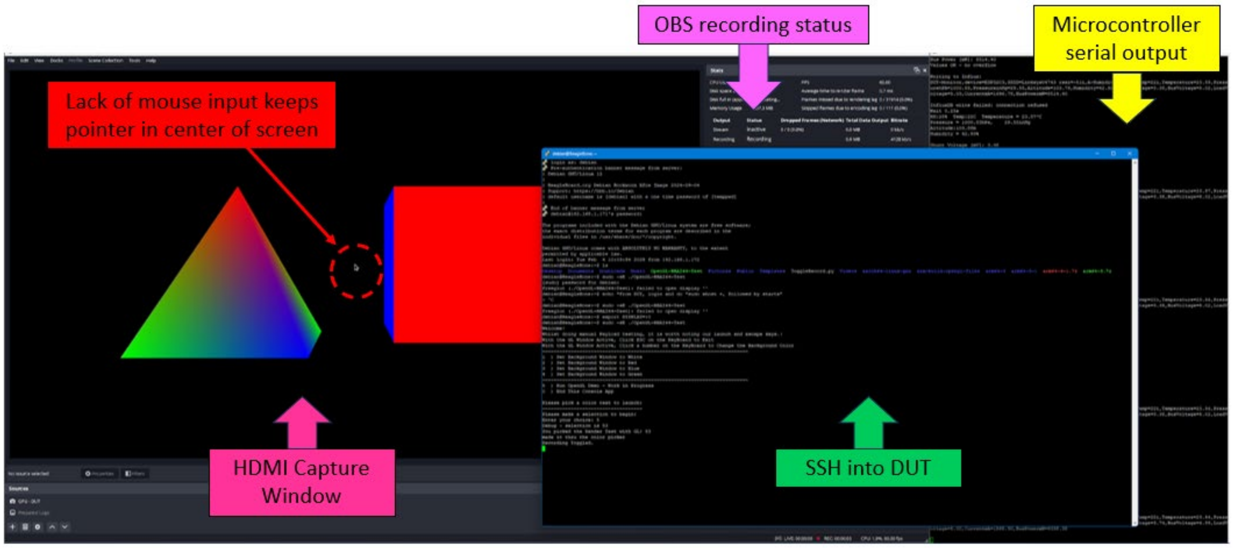


Figure 7: GPU Monitoring Setup using OBS

The Vulkan rendering test was executed by a Raspberry Pi 4b on the test bench network connected to the BBAI-64 by secure shell (SSH) using a terminal. This test launched the graphics window on the BBAI-64's display which was subsequently captured by OBS.

8. Test Results

Failures of an electrical nature (high current draw about 2.5A) and SEFIs instituted an immediate power-off and power-cycle of the device. Current draw above 2.5A was a clear indication that a latch-up event took place causing system failure or instability. A total of 43 test runs were completed. The majority of the test runs ended in a SEFI failure and were used to assess the radiation response via cross section metric for the device. The data for each test configuration (IDLE vs Graphics) was binned and the test data across both test campaigns was aggregated to show the total response for the device. The SEFI cross section for each Linear Energy Transfer (LET) (MeV cm^2/mg) is shown in Figure 8 and Figure 9.

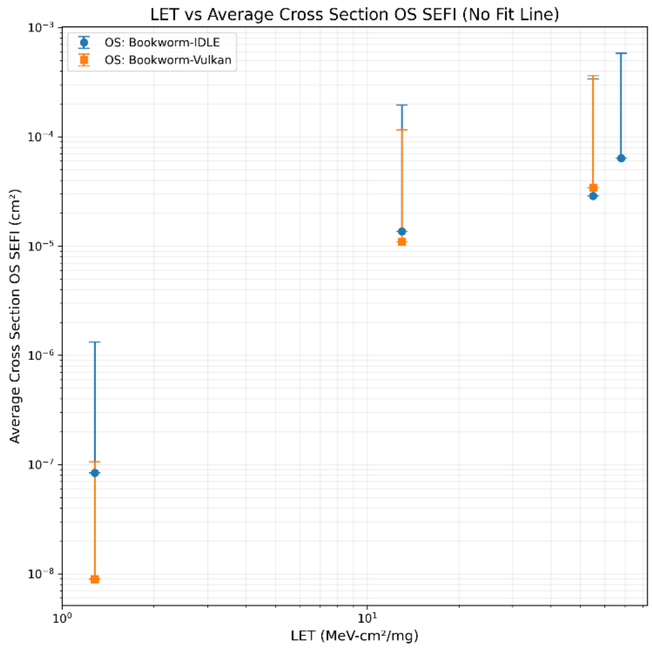


Figure 8: SEFI Cross Sections for all Vulkan and Idle test conditions with Poisson 95% confidence intervals

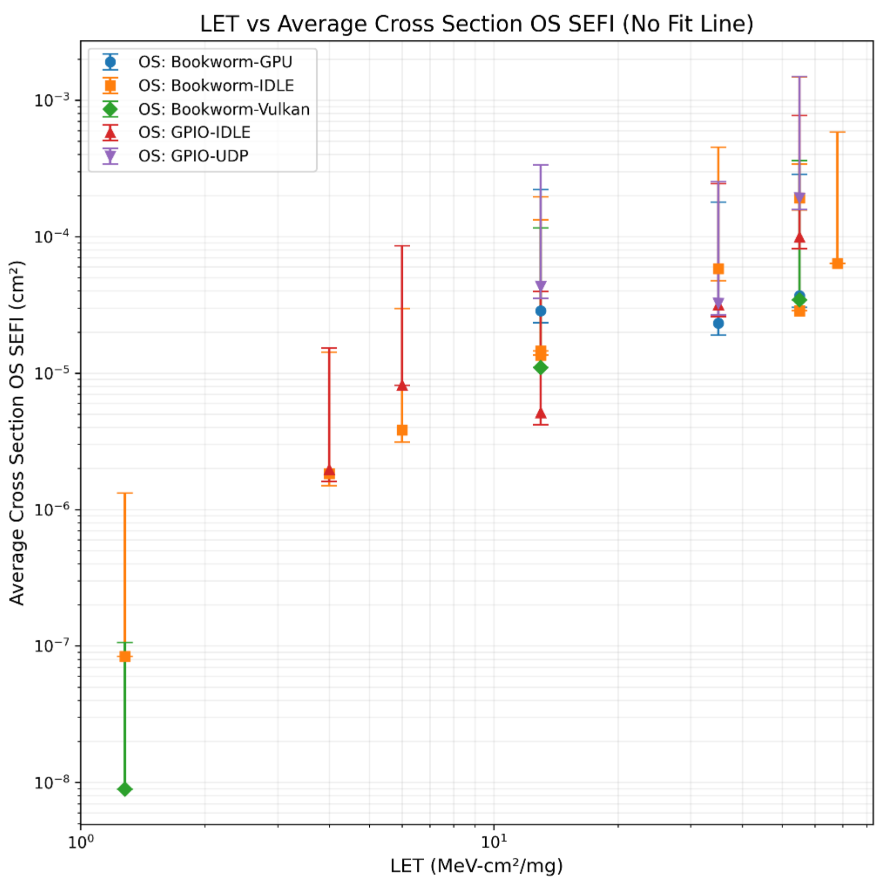
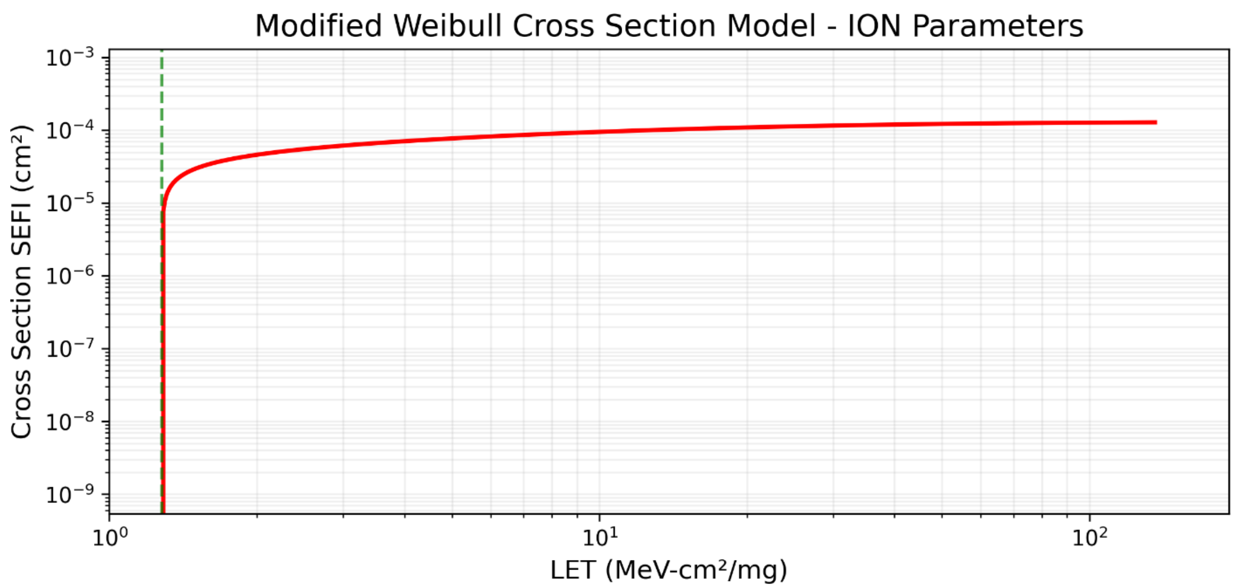


Figure 9: SEFI Cross Sections for all test conditions with Poisson 95% confidence intervals

The results of this test show that the TI TDA4VM system on chip can operate in a space environment if an electrical monitoring system is present. All effects seen either forced the system to reset on its own or had a notable difference in actual current draw versus what was expected during the mode of operation of the device under test. This device aligns well with other microprocessor tests [5, 10, 11, 12] saturating at a cross section approximately 1E-4 cm^2.

Table 3: Weibull Parameters for the TI TDA4VM SoC



Onset LET (Threshold)	1.28 MeV·cm²/mg
Saturation (Limiting) Cross Section	1.3022e-04 cm²
Shape	0.440
Width	4.752

[10] EdgeCortix SAKURA-I Machine-Learning, PCIe Accelerator SEE Heavy Ion Test Report. S. Roffe. NASA 2024. https://ntrs.nasa.gov/citations/20240015800

[11] Recent Radiation Test Results on COTS AI Edge Processing ASICs. M. Casey. NASA 2022. https://ntrs.nasa.gov/citations/20220009215

[12] Proton and Heavy Ion SEE Data on NVIDIA and AMD GPUs. M. Cannon. IEEE NSREC 2023. https://ieeexplore.ieee.org/document/10265847

9. Appendix

The following figures show an exemplar sampling of different types of errors recorded for the GPU versus the expected display output. These behaviors indicate that a buffer redundancy scheme must be employed when using Vulkan or other heavy resource graphics frameworks to assure they update the frame buffers with good data and refresh the frames often enough to scrub corrupt bits.

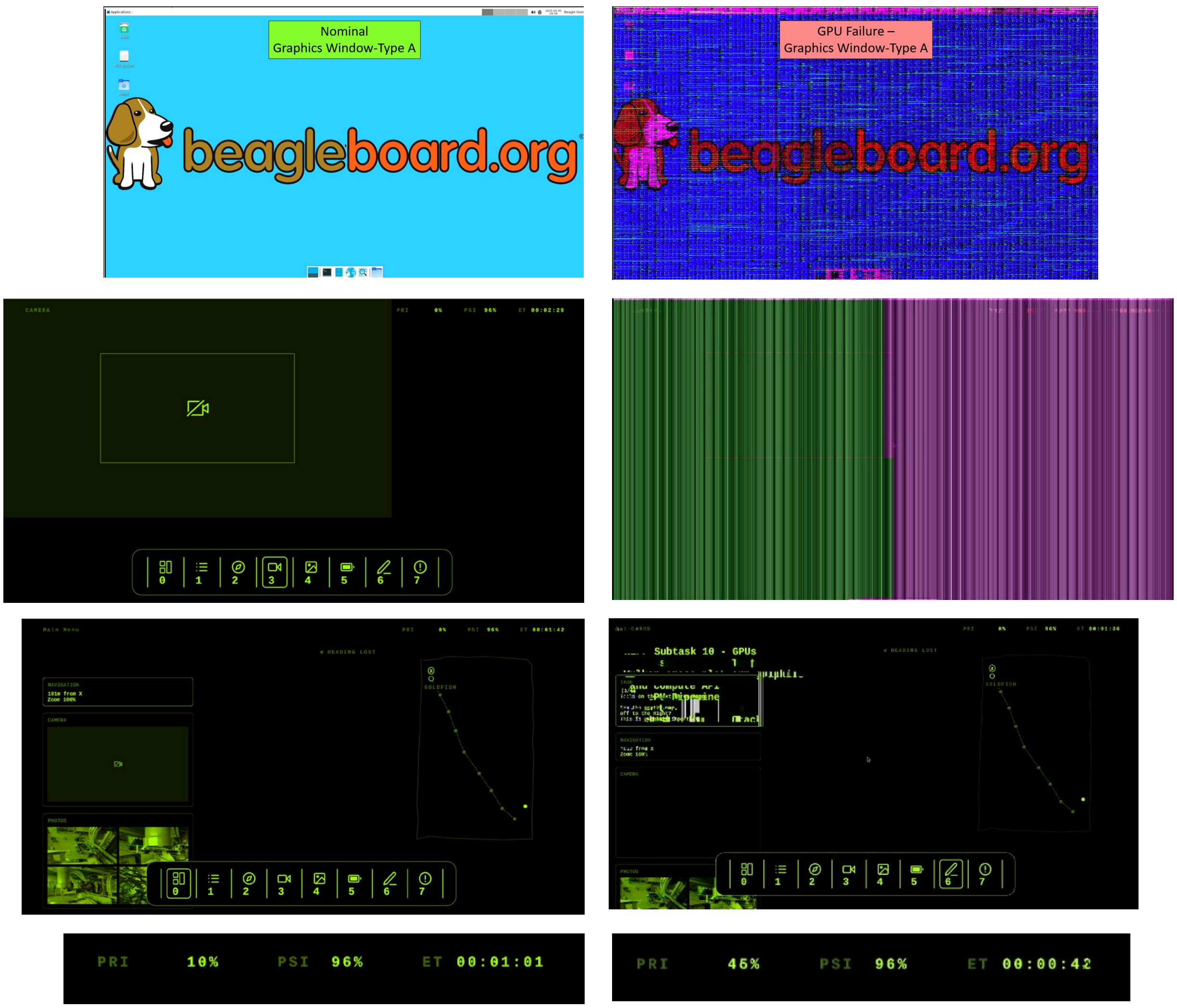


Figure 10: GPU Error Signatures for Vulkan and Idle Tests

The data from the InfluxDB was exported for assessment using Python and interactive plots so that individual test runs, and smaller time window sampling could be focused on. The following figures show two levels of electrical instability which are indicative of latch-up events. The modes of operation are indicated as well as the region of the comparison for the data in the plots.

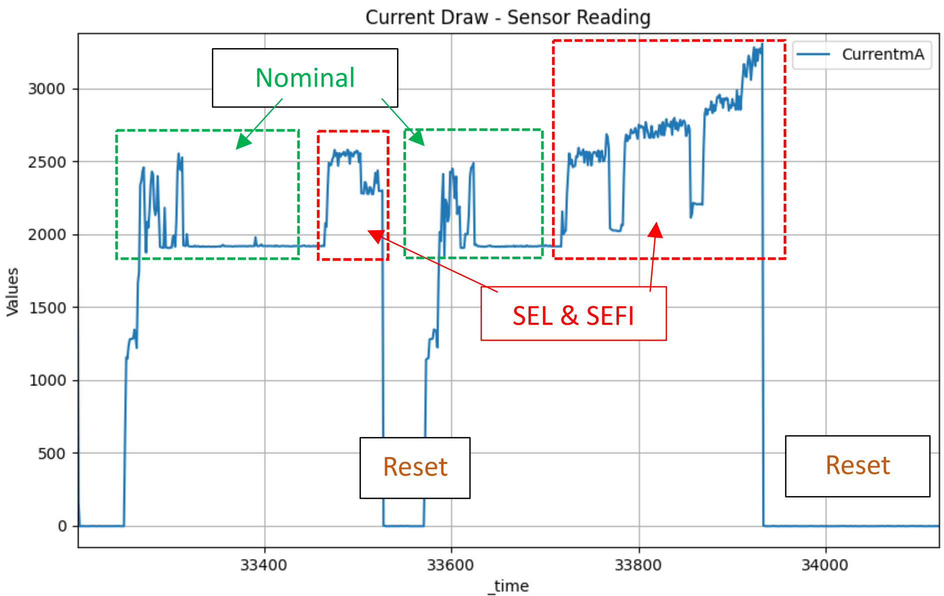


Figure 11: Large Electrical Anomaly indicating Single Event Latch-up and Single Event Functional Interrupt

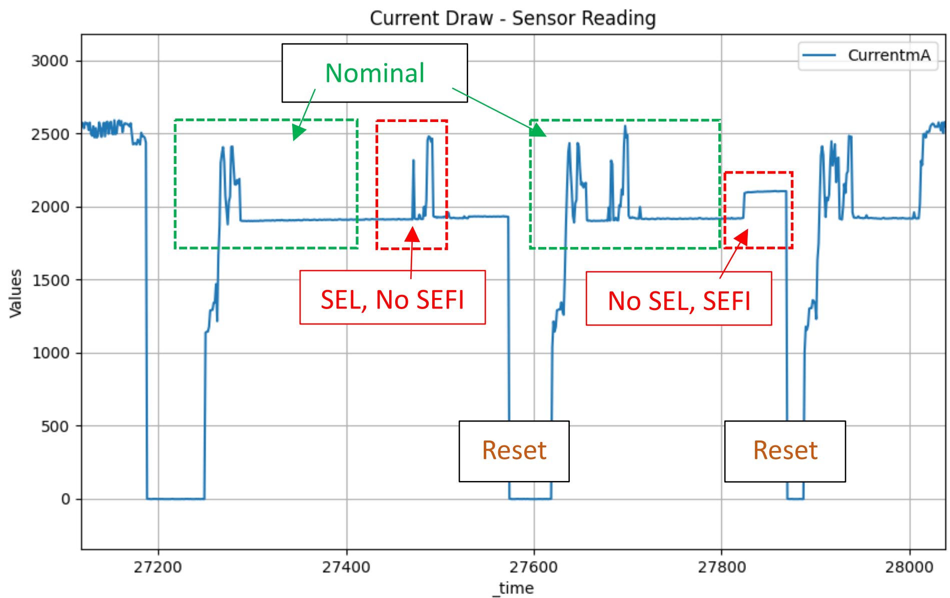


Figure 12: Small Electrical Anomaly indicating Single Event Latch-up with and without Single Event Functional Interrupt

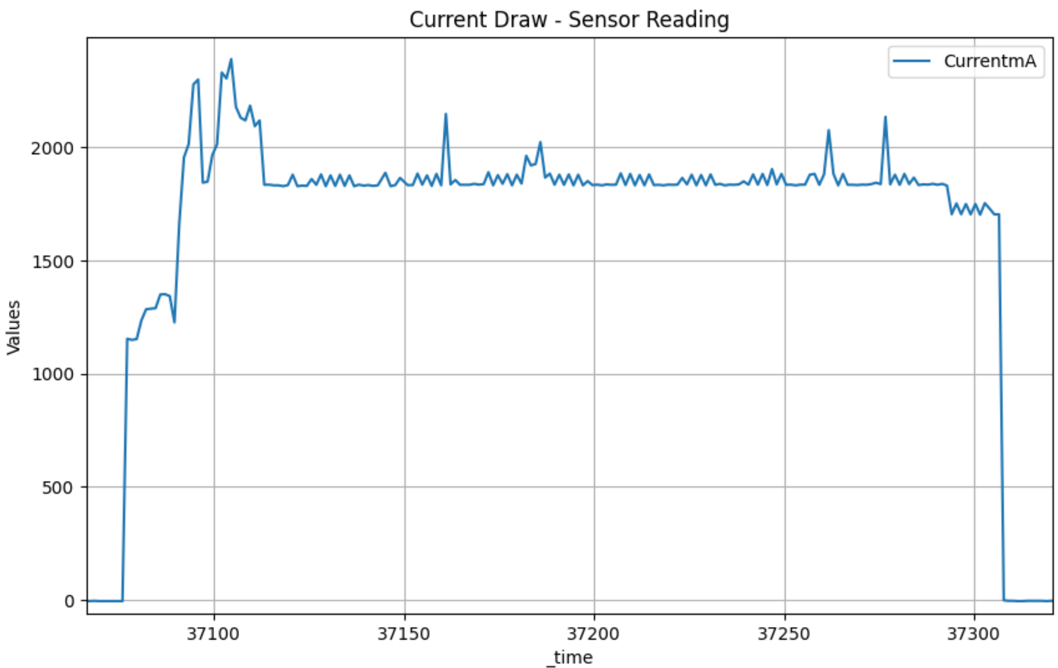


Figure 13: "Electrical Ringing" behavior indicating a failed USB bus (No test routine and No Beam)