Radiation Test Board

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Concept of Operations

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Concept of Operations
for
Radiation Test Board

Team 40

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1. Executive Summary

In the space environment there are multiple radiation sources such as solar radiation, galactic cosmic rays from outside our solar system, and radiation belts that may surround planets like magnetic fields. All of these radiation types in the space environment [1] could have an impact on a vessel and the scientific devices onboard. Therefore, scientific devices designed for space missions are required to undergo radiation testing so that their capabilities can be certified “space-grade” before deployment. The industry’s latest radiation testing processes accomplish this task but are still not meeting the demand for device certification. Texas Instruments currently does radiation testing of their devices at the Texas A&M University Cyclotron Institute. TI has requested a Radiation Test Board that seeks to improve upon the latest methods of radiation testing when it comes to testing efficiency and throughput. The Radiation Test Board consists of a hardware-based apparatus fitted with the configured to measure a device’s response to heavy ion beams via a temperature and humidity sensor and a magnetic (current) sensor.

2. Introduction

The purpose of this document is to present the Radiation Test Board which is a test board that has multiple spaces for devices that can be switched in between to measure the data collected from a temperature sensor when it is under an ion beam. The purpose of the project is to improve lab testing time and reduce configuring the devices once setup has been completed when testing different devices. The result of this can improve the feedback for electronics in high-radiation environments which in return can improve the reliability of the electronics.

2.1. Background

As commercial space flight becomes a reality, demand for semiconductors that work reliably in a high-radiation space environment increases. Texas Instruments has played an instrumental role in the development of space-grade semiconductors for a large portion of space-flight history. Some examples of important space projects that Texas Instruments products on board are every space shuttle mission from 1981 to 2011 and the Mars Rover [2]. To uphold this standard, Texas Instruments continues to produce space-grade semiconductors to be used for spacecraft. However, current testing for semiconductors is tedious and time-consuming due to the ability to only test one specific device at a time.

Texas Instruments tests for single event effects (SEE) in their semiconductors. A SEE can be split into two different types of effects: single-event latch-up (SEL) and single-event transient (SET). An SEL event is what occurs when the device between the power and ground observes a low-impedance path which can be catastrophic for the device under testing (DUT) as it remains latched until power is removed or the DUT suffers damage [2]. A SET event is when the current/voltage of the DUT observes an incorrect voltage level but eventually recovers to the right state. Being able to reduce SEEs or mitigate sudden changes increases the reliability of the device and improves the confidence of the customer purchasing the device.

An example of an existing test board is the TMP9R00-SP, which is a test board that tests if an SET event occurs from the DUT [3]. The test board was developed by Analog Devices and in their test report, it states that the board mounted two different DUTs on the board and a tester monitors both of the DUTs independently. From this, it seems as if both DUTs are turned on at the same time. Issues with this board that this project aims to improve on include the number of DUTs able to test on the board and the ability to record the temperature of the DUT with swappable temperature sensors.

Currently, there is no board to easily swap out a temperature sensor and one with multiple sensors on one board. The ability to swap out the temperature sensors easily makes the process of testing multiple different types of temperature sensors without creating a new board for the sensor create more efficiency and less time in the lab testing. This saves time and cost for reserving the time to test the system.

2.2. Overview

The test board consists of three main components: a power supply, a multiplexor control board (MC board), and the MCU. The power supply will supply power to different devices in the test board. The power supply will send power to a power switch that uses a demultiplexer to power the sensor recording the data and the DUT. This power will be supplied using a PXI power supply that will supply the power while recording the voltage and current. The MC board also contains two demultiplexers that control which DUT is being tested. One demultiplexer controls the power sent to the DUT and sensor capturing data, and the other controls which heating pad corresponding to the DUT should turn on. A thermistor will help regulate the individual heating pad which the heating pad will supply up to a temperature of 175 Celsius. The last component is the MCU. The MCU will be used to capture data from the sensor and current/voltage from the DUT to record for SEE testing. The MCU will be connected to an ethernet cable to send to the monitoring room where the MCU will be connected to a computer for data analysis. In figure 1, it shows the different subsystems and in figure 2, it shows the subsystems in detail as mentioned above.

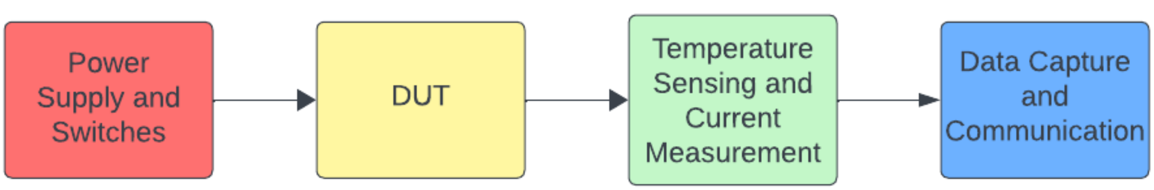

Figure 1 - Simple Subsystem Flow Diagram

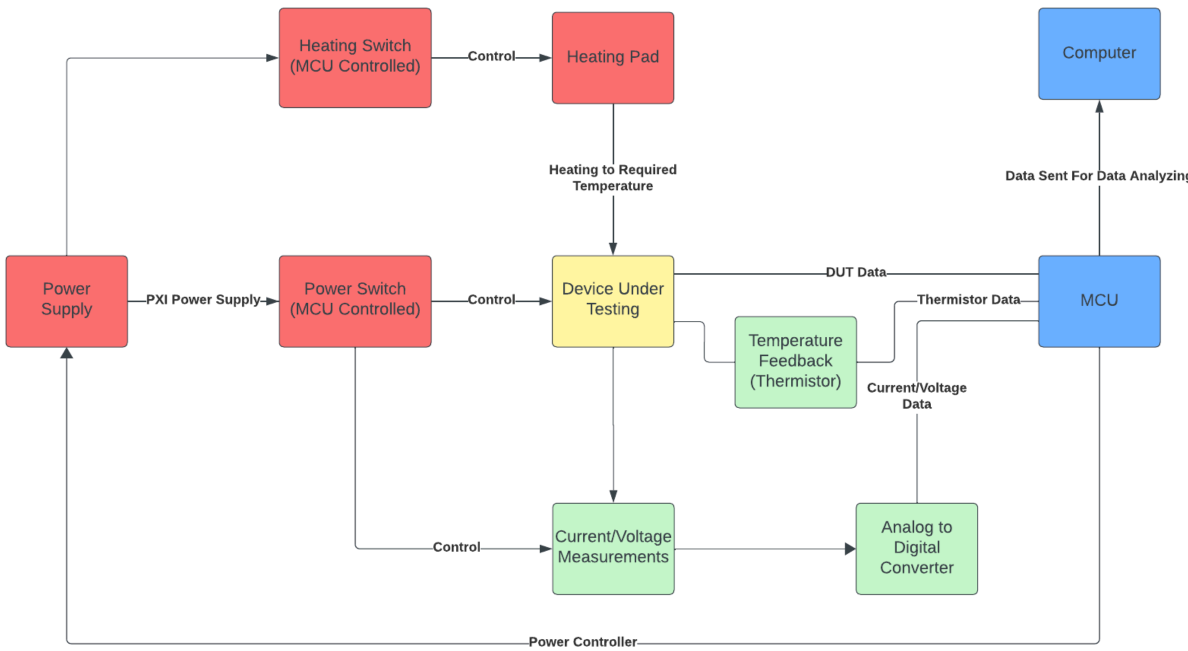

Figure 2 - Expanded View of Subsystem Tasks Color Coded By Subsystem

2.3. Referenced Documents and Standards

[1] E. G. Stassinopoulos and J. P. Raymond, “The space radiation environment for electronics,” Proc. of the IEEE 76(11), Nov. 1988, pp. 1423-1442.

[2] Baumann, R., & Kruckmeyer, K. (2020). Radiation Handbook for Electronics. Texas Instruments.

[3] Vigreux, C. (2016). (rep.). *SINGLE EVENT LATCH-UP TEST REPORT ADCLK925S*. Analog Devices.

[4] G. Bruguier and J-M. Palau, “Single Particle-Induced Latchup,”IEEE Trans. Nucl. Sci. 43(2), April 1996, pp. 522-532.

3. Operating Concept

3.1. Scope

The proposed Radiation Test Board is designed to enable TI to develop a more efficient process for conducting radiation testing. The scope of the Radiation Test Board is as follows:

- Design, build, and validate a test solution to perform Radiation Single Event Effects (SEE) Testing at Cyclotron.
- Configure a Printed Circuit Board.
- Develop an easy setup to capture data for Analog, Digital IO, and i2c communication.
- Develop die temperature monitoring elements.
- Develop adjustable power and voltage/current monitoring elements.
- Analyze the different temperature sensors available on ti.com.

TI should be able to perform Radiation SEE Testing for multiple devices during a session using the Radiation Test Board.

3.2. Operational Description and Constraints

The designed purpose of the Radiation Test Board is to enable scientific monitoring and measurement of several devices during a testing session at Cyclotron.

The radiation test chamber has the following specifications:

- K500 Superconducting Cyclotron
- Target Board dimensions of 10 inches by 10 inches (100 square inches)
- Target Stage with Clamp for Target Board
- Heavy Ion Target Area of 4 square centimeters

“At the heart of our cyclotron is a superconducting magnet whose intense magnetic field holds the ions in orbits between its poles. The 50 kilogauss magnetic field is generated by 800 amperes of electrical current carried by 5500 turns (25 miles) of niobium-titanium superconducting wire in a coil surrounded by 100 tons of steel. The acceleration of the ions is accomplished by intense, rapidly alternating electric fields generated by a 240-kilowatt radio-frequency system and impressed upon hollow copper structures called dees located between the poles of the magnet. The generation, injection, acceleration and delivery to the target of the ions takes place in high vacuum, while the path and focus of the beam outside the cyclotron is controlled by high-field electromagnets.“ (Ref. cyclotron.tamu.edu)

The Radiation Test Board is designed with the intention for use at Cyclotron. If TI desires to use the Radiation Test Board in a different facility, changes to the Radiation Test Board or the associated methods may be necessary.

3.3. System Description

The design of the Radiation Test Board is allocated into 3 distinct subsystems:

1. **Power and Temperature Controls**

    A power signal will be supplied via a PXIe-4139 system source measuring unit (SMU) to an adjustable DC/DC Converter (Power Switching Circuit) and a different DC/DC Converter (Temperature Controls Circuit). The MCU will be powered via a separate power supply. A DAC will modulate the signal based on each DUT via MCU controls; this enables the DC/DC Converter to become "adjustable." The user will select a target board and the MCU will tell the Power Switching Circuit to supply the modulated signal to the correct target board. The respective heating pad will begin increasing DUT temperature (Temperature Controls) in parallel with the Power Switching Circuit via MCU signal. Firmware will need to be developed so that the DAC can be used to make the DC/DC converter "adjustable" and for MCU communication with the Power Switching Circuit and the Temperature Controls. All of these operations will be implemented on a PCB.

2. **Sensors and Feedback**

    A temperature sensor that is powered from the power supply unit measures the temperature of the DUT and sends that information to the microcontroller using i2c communication protocols. A current sensor and voltage sensor powered by the power supply measures the current coming from the DUT and sends that analog signal to an ADC to be converted to a digital signal which will be sent to the microcontroller for data processing. The information from the DUT will also be sent to the microcontroller to read the value of the DUT. Firmware needs to be developed to control the ADC control signals and the temperature and current/voltage sensor's control signals.

3. **Microcontroller Firmware**

    Custom MCU Design, Ethernet Implementation, Firmware for communications and general application support, Communications via Telnet (ASCII). MCU will have ESP32 WROVER E N16R8 chip. MCU will communicate with the monitoring room computer via ethernet cable. MCU will manage the power controls for heating pads and DUTs using I/O pins to switch between different devices, and SPI Pins to communicate with the DAC, as according to instructions from the monitoring room. MCU will receive data from temperature and voltage/current sensors using I2C. Data will be stored on the internal 16 MB flash memory of the WROVER chip. All of these operations will be implemented on a PCB.

3.4. Modes of Operations

3.4.1. Off Mode

The power supply is off and not powering any components or devices. The DUTs are at room temperature and the sensors are offline. The heavy ion beam is offline.

3.4.2. Warm-Up Mode

The power supply and board are powered on. Power is being supplied to the heating pads, the DUT, and the MCU. However, the heating pads and DUT have not reached the requisite temperature yet. The board is not ready to receive heavy ion beams.

3.4.3. Standby (Testing) Mode

Standby mode is when the board is powered on. Power is being supplied to the heating pads, the DUT, and the MCU. The heating pads and the DUT have reached the desired temperature. The board is ready to receive heavy ion beams.

3.5. Users

The target user for the Radiation Test Board is a company, such as Texas Instruments, that has devices they want to be certified for space-grade implementations. The Radiation Test Board can enable a company to effectively test their devices so that the most amount of devices can be tested during a session. The target user should have experience with Radiation SEE testing and the common methods associated with testing.

3.6. Support

Support documentation for the Radiation Test Board will be provided via a User Reference Manual. The User Reference Manual will include instructions on implementing the Radiation Test Board into the current radiation testing methods and general upkeep.

4. Scenario(s)

4.1. SEL Occurrence

The supply current is monitored for latchup events [4]. In case of a single event latchup, the time the latchup was detected, the current will be recorded, and power to the DUT and the heating pad will be cut. The operator will also be notified of the SEL occurrence.

4.2. SET Occurrence

In the case of an SET occurrence, the change of state will be recorded and power will continue to be supplied to the DUT and heating pad. The test will not be interrupted.

5. Analysis

5.1. Summary of Proposed Improvements

- The Radiation Test Board will support the methods for radiation testing that TI has been conducting at the Cyclotron Institute. The methods for collecting data from the Radiation Test Board can provide evidence for a proper understanding of each scientific device, respectively.
- The Radiation Test Board will provide a means to test multiple devices during a session at the Cyclotron Institute,without having to physically manipulate the board between runs. This helps TI meet the client demand for radiation testing and verification.

5.2. Disadvantages and Limitations

- The design of the Radiation Test Board is still limited by the constraints of the Cyclotron test environment. The Stage Frame, which can be attached to the Stage, has a length and width of 10 inches and an area of 100 square inches. As a result the MC Board (Multiplexor Control Board) must have an area less than 100 square inches.
- One inch margins are required between each DUT to maintain test integrity. This limits the total number of Targets Boards to the size of the MC Board
- The number of Target Boards must be configured according to the size of the MC Board. Each Target Board does have dimensions much less than of the Stage Frame but it is important to reiterate the fact that all the Target Boards must collectively fit onto the MC Board configuration.

5.3. Alternatives

Some alternative design considerations include each target board having more than one sensor collecting data (i.e., a primary and secondary sensor). For example, a primary sensor (such as a digital current sensor) could work alongside a secondary sensor (such as an analog current sensor). One benefit of this design is that the primary sensor’s data can be validated from the collected data from a secondary sensor.
Another alternative embodiment may include more target boards than the proposed design. The advantage of this design is to minimize the number of times the user has to walk from the monitoring room to the testing room. Increasing the quantity of target boards enables the user to verify data from each run without executing multiple runs. More device testing allows the user to decrease the number of times they physically move from the monitoring room down a set of stairs to the testing room.

5.4. Impact

An accelerated method for space-grade device certification could stimulate innovation by potentially lowering the cost of radiation testing, at least from a per-device perspective. Both industry leaders and small firms should agree that decreasing expenses, especially in this case, is in the best interest of all involved parties. The proposed Radiation Test Board configuration allows TI to seek partners to split costs if Cyclotron does not change its billing structure for heavy ion testing (i.e., based on the number of DUTs).