A CubeSat Platform for Characterizing the Reliability of Electronic Components

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***Abstract*—Because the space environment's effect on the operation of affordable, commercially available components is not well characterized, these devices are often ignored as viable candidate parts. This paper presents the design of the CubeSat Reliability Experiment (CRX) platform, a 1U customizable CubeSat-compatible system built to test and validate a variety of commercial off-the-shelf electronic components through direct exposure to the space environment. The system reports measurable device under test (DUT) health and environmental characteristics to the spacecraft bus. Data comparisons between shielded and exposed DUTs indicate DUT reliability. This work discusses the CRX system architecture as well as the demonstrated prototype implementation of hardware and software designs for a MOSFET DUT. This mockup establishes the system as an effective, low-cost utility to expand the list of qualified space-ready parts by determining accurate reliabilities of COTS components.**

I. INTRODUCTION

Currently, space-qualified electronics for use on spacecraft are costly and outdated, in large part because of the effort and expense required to prove their robustness to the space environment [1], [2]. Alternatively, more affordable, commercially available components may be viable options, but because their performances in the space environment are uncharacterized, these devices are dismissed in the spacecraft design process. The CubeSat Reliability Experiment (CRX) provides a customizable platform compatible with a 1U CubeSat that is ideal to test and validate a variety of commercial off-the-shelf (COTS) electronic components. Since functionality is measured from actual flight, the Technology Readiness Level of operable COTS parts may advance, allowing more COTS to be incorporated into the NASA Parts Selection List and providing designers with more capable and cost-efficient options for future space missions.

CRX consists of the COTS tested parts, a radiation protective enclosure, two printed circuit boards (PCBs), and an Arduino Uno. The protective enclosure was designed to provide adequate protection against space weather effects, integrate easily with the CubeSat, and be simple for manufacturing and assembly purposes. Situated within the shielded enclosure and underneath the PCB mainboard, the Uno varies certain electronic parameters of the circuit to test the devices under test (DUTs). Furthermore, the Uno receives DUT health characteristics and is responsible for sending this data to the CubeSat bus. CRX PCBs are populated with a control group and a test group of DUTs and their accompanying electronics. Data comparisons of the separate groups reveal the effect of the space environment on DUT performance. Protected by the enclosure, the PCB mainboard contains control DUTs and should include as much of the additional circuitry as possible to prevent damage to non-DUT devices. Figure 1 portrays a section view of an assembly consisting of two shield housings sandwiching a PCB board and mounted Arduino Uno. An external PCB, exposed to the space environment, supports test DUTs and a radiation monitor to measure dose-rate and equivalent accumulated dose (TID).

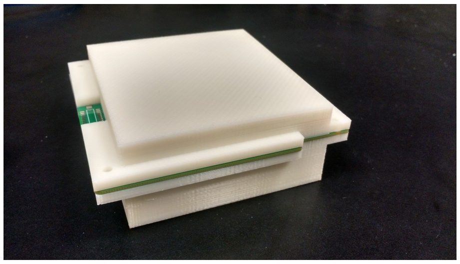

Fig. 1: Shielding assembly section view featuring a 3D-printed shield enclosure, PCB mainboard, and enclosed Arduino Uno.

II. DUT HARDWARE CONFIGURATION

Though CRX is capable of accommodating a variety of DUT types, the MOSFET was selected to initially demonstrate the system. MOSFETs are integral to modern electronics as they are popular transistor elements in analog and digital circuits. Radiation exposure has several effects on MOSFETS including shifting threshold voltages, affecting the subthreshold slope, decreasing transconductance, and increasing gate-induced drain leakage current and noise [3], [4]. Thus, their functionality can be tracked by observing the dependence of the source / drain current on different gate voltages over time.

Figure 2 shows a high-level circuit schematic of an individual DUT circuit placed on the CRX mainboard. The eight MOSFET CRX system essentially replicates the same circuit eight times, but with the DUT and R_{DUT} on either the main or external board. Expanding the design to the multi-DUT configuration requires a duplication of all the devices in the schematic with exception to the Uno, I/O Expander, analog-to-digital converter (ADC), and digital-to-analog converter (DAC) as they shared for the entire CRX system.

Harnesses run power and data connections from the CubeSat

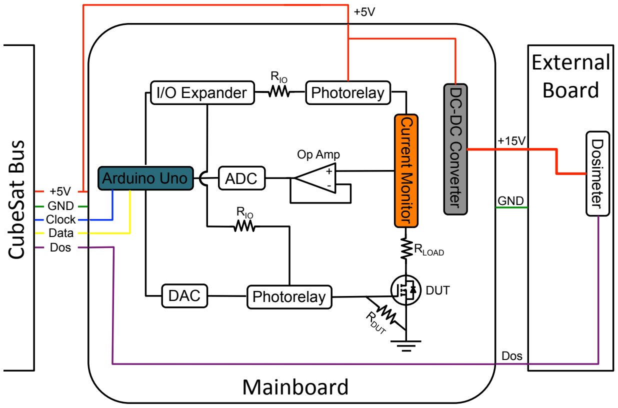

Fig. 2: CRX MOSFET circuit design schematic for one DUT placed on the mainboard.

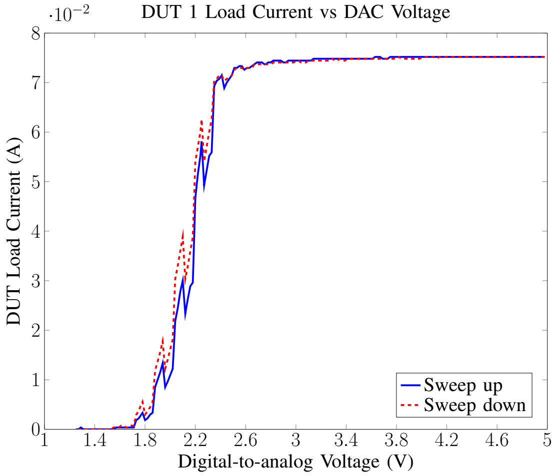

Fig. 3: DUT 1 Load current vs DAC voltage.

bus to the mainboard and from the mainboard to the external board. The Uno uses an I/O expander to select one of the eight DUTs and the digital-to-analog converter (DAC) to apply a voltage on the MOSFET gate. A current monitor measures the MOSFET source / drain current and feeds a proportional output voltage to the operational amplifier, which acts as a buffer. The signal is then sampled by the analog-to-digital converter (ADC) and is relayed by the Uno back to the CubeSat. The external PCB board is designed for Teledyne Microelectronics Technologies' UNDOS001 micro dosimeter. However, with a supply voltage range of 13 V - 40 V, a DC-DC converter is required to boost the CubeSat supply of 5 V to the sensor's operational range.

III. ARDUINO UNO SOFTWARE

The Arduino software carries out DUT health tasks and reports the associated response. The MOSFET configuration software is comprised of two different codes: a master and slave. For testing purposes, a separate Arduino Uno acting as the CubeSat bus contains the master code and requests data from and sends commands to the slave CRX Uno attached to the mainboard.

The slave device code, i.e. that on the CRX mainboard, is responsible for reporting and tracking the DUT functionality. Reporting is achieved by sending the master the active DUT number, the applied DAC voltage, the current monitor output voltage, and the DUT source / drain current at the time the slave was probed. These values were sent as part of a byte array from the slave referred to as the ADCRequest array. DUT performance is gauged by cycling the DAC output voltage in sweeps from 0 V to 5 V and back to 0 V in 0.02 V increments. The increment value provides adequate resolution in the MOSFET Load current vs. DAC output voltage plot as seen for DUT 1 in Figure 3.

The cycle, however, is only performed on active DUTs introduced by a command from the master device. Upon activation, a cycle of DAC voltages begins, i.e. 0 V to 5 V to 0 V. It is important to note the slave auto-increments the DAC voltage and DUT number after the slave has been queried. This prevents any potential timing issues that could arise if the DAC, DUT, and query schedules were out of sync.

Acting as a surrogate for the CubeSat bus, the master device code has several purposes. Foremost, the code queries the slave every two seconds to obtain and display the ADCRequest array. In addition, the master code has some user defined or "bus" interrupt capabilities. At any time, the user can toggle the state, activated or disabled, of any DUT (1-8). Once a DUT is activated, a sweep cycle of that DUT will begin before incrementing.

IV. CONCLUSIONS

This work outlines the design methodology and capability of a functioning prototyped CRX MOSFET system. By leveraging low-cost hardware and frequent CubeSat launch opportunities, commercial off-the-shelf parts can be qualified for use in the space environment at a discounted rate when compared to tradition methods. Consequently, the addition of these components to the NASA Parts Selection List enables engineers to create a better and cheaper spacecraft.

ACKNOWLEDGEMENT

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