

Single-Event Effect Testing of the Broadcom ACPL-785E Optocoupler

Michael J. Campola

Anthony M. Phan

Landen D. Ryder

Christina M. Seidleck

Thomas A. Carstens

NASA STI Program Report Series

The NASA STI Program collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

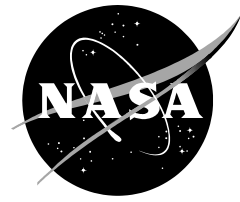
- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- Help desk contact information:

<https://www.sti.nasa.gov/sti-contact-form/> and select the "General" help request type.



Single-Event Effect Testing of the Broadcom ACPL-785E Optocoupler

*Michael J. Campola
Goddard Space Flight Center, Greenbelt, MD*

*Anthony M. Phan
Science Systems and Applications (SSAI), Inc., Lanham MD*

*Landen D. Ryder
Goddard Space Flight Center, Greenbelt, MD*

*Christina M. Seidleck
Science Systems and Applications (SSAI), Inc., Lanham MD*

*Thomas A. Carstens
Goddard Space Flight Center, Greenbelt, MD*

*Test Date: 12/19/2020
Report Date: 12/15/2021*

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

January 2022

Acknowledgments

This work was sponsored by the NASA GSFC Radiation Effects and Analysis Group and supported by the On-Orbit Servicing, Assembly and Manufacturing (OSAM-1) mission.

Trade names and trademarks are used in this report for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA STI Program
Mail Stop 148
NASA's Langley Research Center
Hampton, VA 23681-2199

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-605-6000

This report is available in electronic form at

<https://radhome.gsfc.nasa.gov/>

1. Purpose

The purpose of this testing was to examine the potential for destructive single event effects (SEE) and single event transients (SET) in Broadcom's ACPL-785E optocoupler in support of a NASA Goddard Space Flight Center flight program. SEE testing was conducted at the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory where devices with unmodified packaging were irradiated with high energy ions that have sufficient range to pass through the packaging of the device.

2. Device Information

The ACPL-785E Hermetically Sealed Analog Isolation Amplifier is designed to provide power and signal isolation between the input and output sides of the device (information is summarized in Table 1). The input side of the device consists of a sigma-delta analog-to-digital converter that is encoded and converted to an optical signal that can be transmitted through a nonconductive polymer via a light emitting diode. On the output side of the device, a photodetector converts the photons from the input side to an electrical signal that is passed through a decoder and digital-to-analog converter and filtered before being output from the device. A functional diagram of the constitutive components of the device is provided in Fig. 1. The devices are constructed such that the input and output side of the devices are fabricated on individual dies resulting in a multilayer configuration with a light emitting diode inverted directly above the photodetector. The devices under test are in unmodified 8-Pin dual-inline packaging (DIP) (Fig. 2A) to ensure device functionality and that the overall system response of the device was being characterized.

Table 1 – Parts Identification Information

Part Number	ACPL-785E
Manufacturer	Broadcom Inc / Avago
Lot Date Code	1649
REAG ID	17-047
Additional Case Markings	Q1649A
Quantity Tested	2
Part Function	Optocoupler
Part Technology	Hybrid
Package	8-Pin DIP

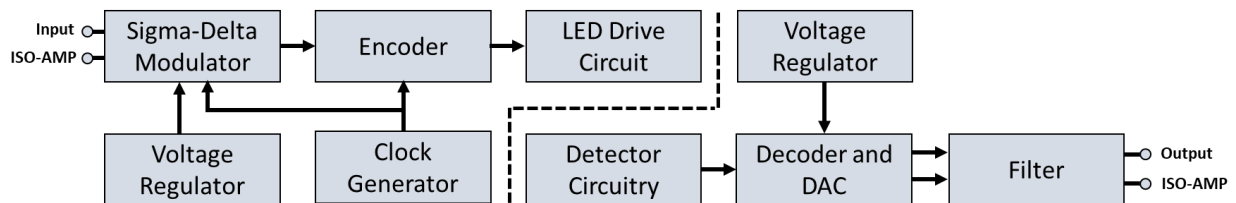
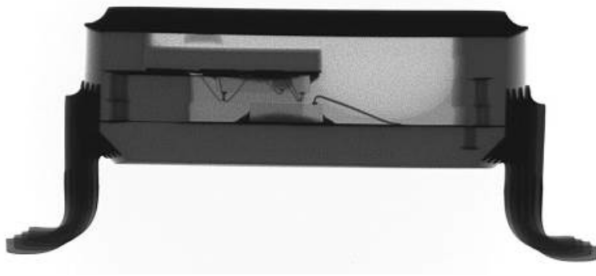


Fig. 1. Schematic representation of ACPL-785E optocoupler as outlined by the manufacturer [1]. Note that the dashed line corresponds to the isolation boundary between the input and output sides.

A)



B)

Material Stack [mm]

Nickel - 0.215
Air - 0.297
A ₂ O ₃ - 0.34
Silicon - 0.356
Epoxy - 0.209
Silicon - 0.356
A ₂ O ₃

Fig. 2. A) X-ray image of the packaged device. Note that the circuit dies are oriented vertically, increasing the amount of material the particles must pass through to reach active silicon. B) Using material analysis and X-ray measurements, an approximate material stack can be constructed for use in estimations.

3. Test Facilities

Facility: NASA Space Radiation Laboratory

Flux: 2×10^2 ions $\text{cm}^{-2} \text{s}^{-1}$ to 1×10^3 ions $\text{cm}^{-2} \text{s}^{-1}$ per beam spill

Fluence (per ion): 1×10^7 ions cm^{-2}

Table 2 shows the ions that were used during irradiation. Note that the particle energy and incident linear energy transfer (LET) are defined prior to interaction with the device. The calculated LET minimum is the LET of the particle at the surface of the silicon estimated via Stopping Range in Matter (SRIM) software on an approximate material stack (Fig. 2B) to compute the impact of the packaging and substrate on the particle.

Table 2 - Ions Used During Test

Facility	Ion	Beam Energy [MeV/amu]	Angle [°]	Incident LET [MeV·cm ² /mg]	Calculated LET Minimum [MeV·cm ² /mg]
NSRL	Ta	155	0	21.00	27.2
NSRL	Ta	140	0	22.20	31.3
NSRL	Ta	125	0	23.78	37.6
NSRL	Ta	120	0	24.00	41.8
NSRL	Au	200	0	21.30	25.7
NSRL	Au	180	0	22.60	30.1
NSRL	Au	140	0	24.20	33.4

4. Test Conditions

Single Event Effects testing was conducted at maximum positive operating voltage values. The device was tested at room temperature and the test conditions are outlined in Table 3.

Table 3 - Test Conditions During Irradiation

Power Supply Voltage	$V_{dd1} = V_{dd2} = 5.0 \text{ V to } 5.5 \text{ V}$
Input Voltage Signal	3.8 V DC signal and a 1 V square-wave with a 1 ms period (50% duty cycle) and 3.2 V DC offset.
Voltage Monitoring	Input (V_{IN_POS}) and output (V_{OUT_POS} , V_{OUT_NEG}) voltages were monitored via an oscilloscope. Any transient events were captured/saved by the oscilloscope when triggered.
Error Modes	Destructive and Non-destructive SEEs and SETs

5. Test Setup

The device under test (DUT) were mounted in sockets and placed in the line of the beam, Figure 3. A function generator was used to provide two variations of input voltage waveforms: a 3.8 V DC signal and a 1 V square-wave with a 1 ms period (50% duty cycle) and a 3.2 V DC offset. An oscilloscope was used to monitor the input voltage waveform and the output voltage channels for transients and any persistent change in signal state induced by an ion strike. The devices were operated in the following circuit configuration in Fig. 3 and mounted in the beam path as depicted in Fig. 4.

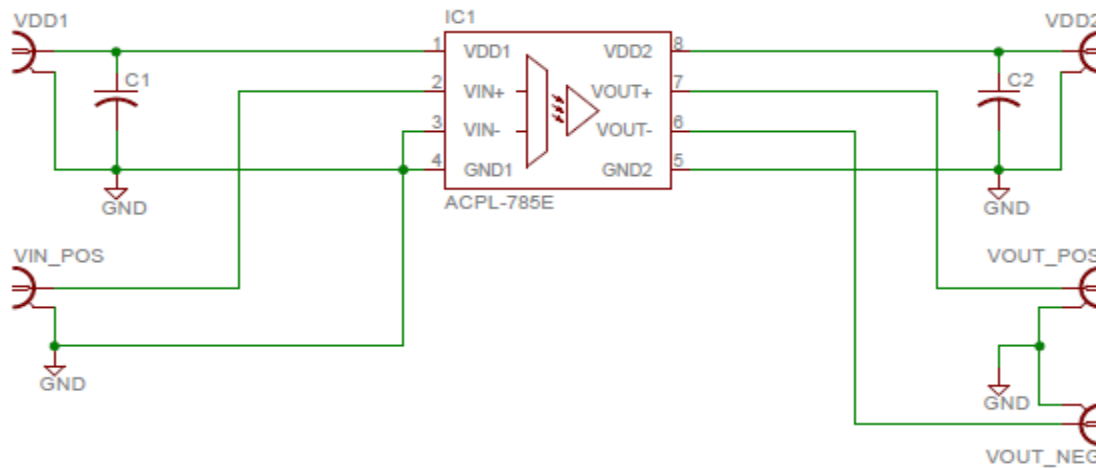


Fig. 3. Measurement circuit schematic for SEE characterization of the ACPL-785E optocoupler.

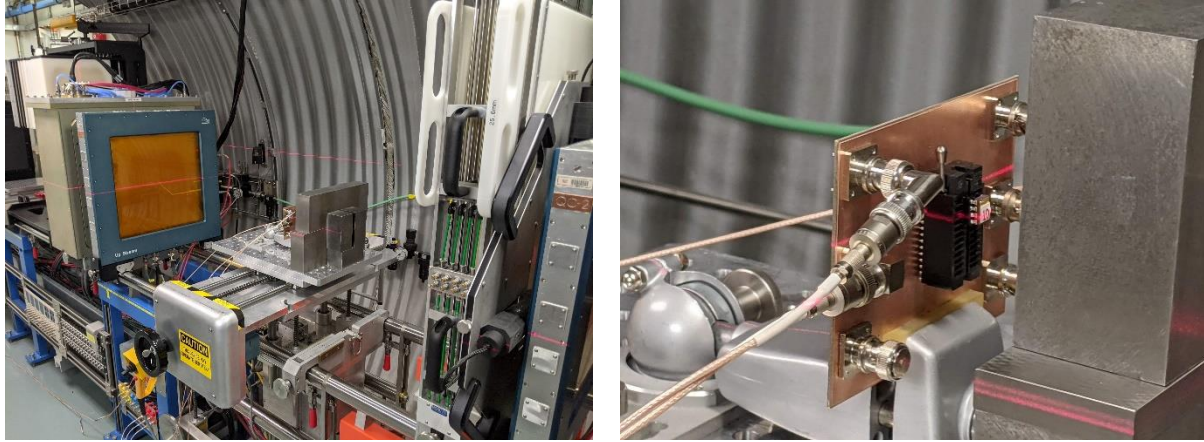


Fig. 4. Device in the beam at Brookhaven National Lab.

6. Test Results

A series of normal incidence heavy ion irradiation was conducted with gold and tantalum nuclei at a variety of energies to achieve an estimated LET range of 22.7 to 41.8 MeV·cm²/mg at the active region of the silicon dies. Initial runs were used to optimize oscilloscope and irradiation parameters. No destructive single event effects were observed during these tests. Following optimization of the experimental setup for transient capture, a fresh device was swapped into the setup and was irradiated. No destructive transients were observed during these tests. For the case of the DC input signal, the DC offset at the output and transients were broadly classified by the duration and amplitude into two categories. The first category of transients is characterized by a short duration opposite polarities, as depicted in Fig. 5A. The second category of transients (Fig. 5B) is characterized by positive polarity transients with greater amplitude and duration than the previous category. As common mitigation techniques rely on the duration and amplitude of the transients, the worst-case transients from each measurement run are plotted in Fig. 6 and the full-width half maximum (FWHM) of the worst-case transients as a function of LET in Fig. 7.

Alongside the expected SET response observed in the DC input signal response (Fig. 8A), SEE testing with the square wave input signal can present in a radiation-induced time delay in one or both output channels (Fig. 8B-D). Transients consistent with the categories discussed previously were observed with and without the signal delay, establishing that the SETs and the signal delay are induced via separate mechanism. While the time delay was variable, the duty cycle signal remained consistent with the input signal and did not result in an abbreviated cycle. Over the course of SEE measurements, the radiation-induced signal delay was observed in a single output channel as well as in both channels concurrently. As the device leverages encoders, converters, and a modulator to better represent an analog input signal, there is a reliance on a timing circuitry than can be disrupted from an SEE.

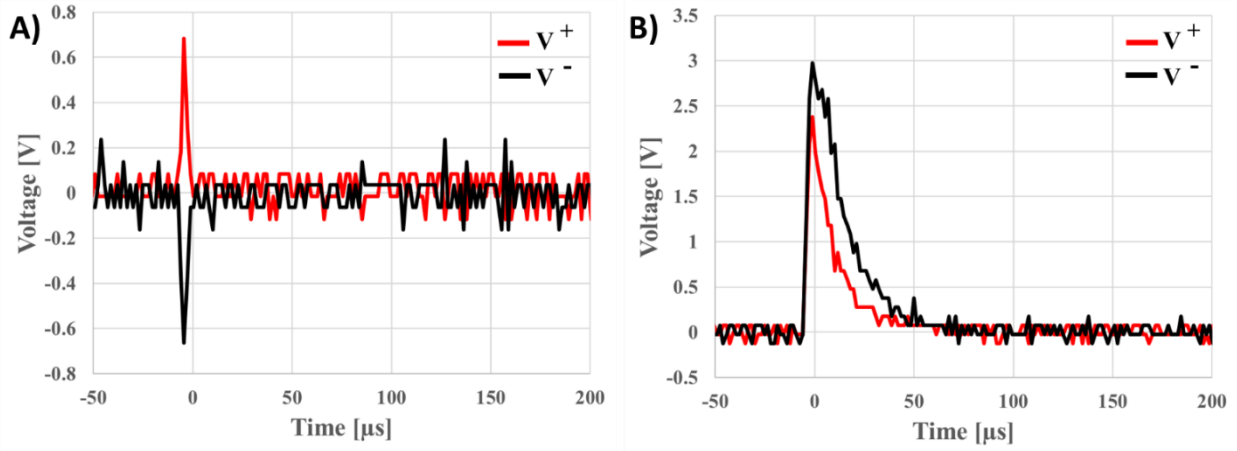


Fig. 5. A) Narrow and B) large SETS observed at an LET of 30.1 MeV-cm²/mg. Note the polarity of the transients.

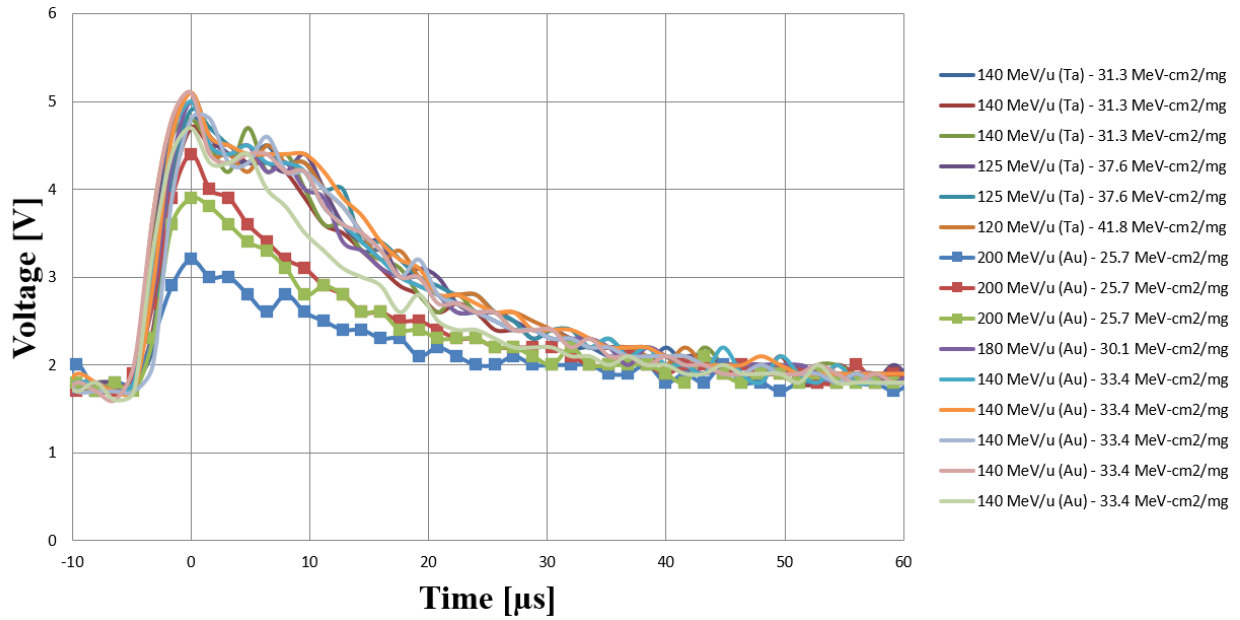


Fig. 6. Largest amplitude transient (V_{OUT_NEG}) from each measurement run with the DC input voltage signal. Note that data points have been added to more easily identify the smaller transients in the legend.

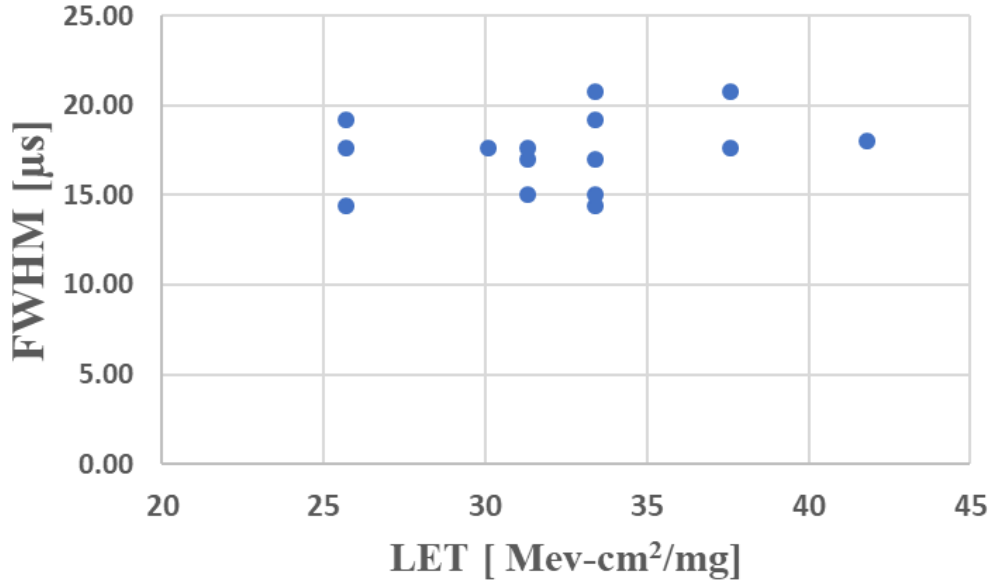


Fig. 7. FWHM of the largest amplitude transient (V_{OUT_NEG}) from each measurement run with the DC input voltage signal.

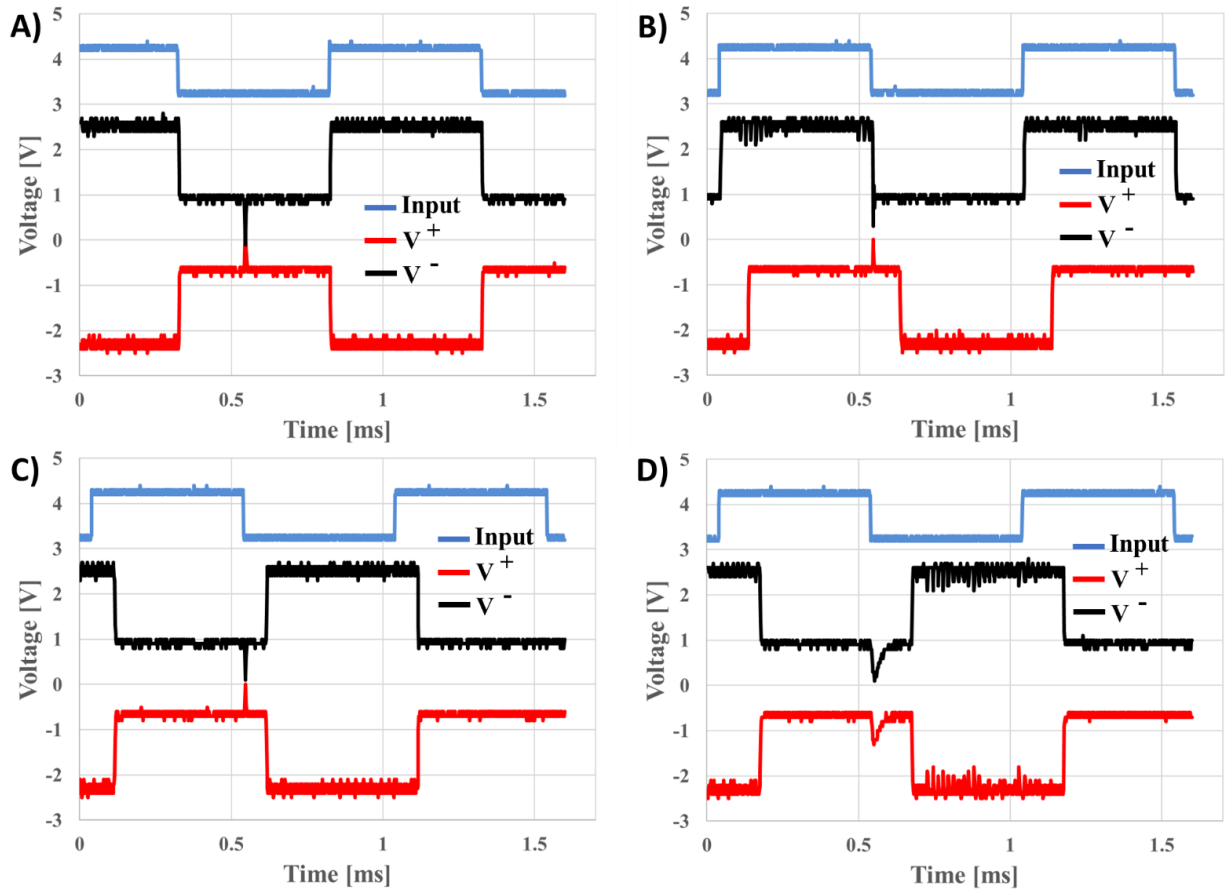


Fig. 8. Example output channels (red and black) measurements during heavy ion irradiation with an input square wave (blue). SETs are observed with the device response to the input signal with A) no radiation-induced delay, B) radiation-induced delay in one output channel, and C) radiation-induced delay in both output channels. The SETs observed in the waveform occur independently of the radiation-induced time phase delay, D) SETs observed in the waveforms demonstrating a range of durations.

7. Summary

Heavy ion SEE measurements were conducted on Broadcom's ACPL-785E optocoupler to screen for destructive SEEs (none observed) and examine SETs up to an estimated LET of 41.8 MeV·cm²/mg at the active silicon of the device. Due to the multilayer construction of these devices, high energy ions at NSRL were required to ensure that particles reach the sensitive region of the device while maintaining device operation. While deconstructing the optocoupler to access the individual dies for testing with lower range particle, the decoupling of the input/output sides obfuscates the characterization of the system level radiation response. SEE testing with unmodified packaging allows for capturing the system response to SEEs induced in individual components that propagate to the output. SETs were observed in the output signal state for both a DC and square wave input voltage signal. Furthermore, a radiation-induced signal delay were observed in the output signal state when an input square wave voltage was applied. These results do not extend to other types of radiation testing, such as total ionizing dose, and were conducted with a specific application circuit design.

8. URLs for Datasheets

[1] <https://docs.broadcom.com/doc/AV02-3479EN>



9. Logs

Run Information				Beam Diagnostics					Part Operation					Beam Actuals						
Run #	Date	Time Complete	DUT #	Energy (MeV/u)	Ion Species	Energy (MeV)	Calculated LET Minimum (MeV-cm2/mg)	Angle (°)	Supply Voltage (V)	Supply Voltage 2 (V)	Input Freq (kHz)	Input Amp (mV)	Output Amp (V)	Flux per spill (cm-2)	Fluence (cm-2)	Eff. Fluence (cm-2)	Dose (l)	Delivered	Total Dose (l)	Notes
1	19-Dec-20	10:10:50	10	155 Ta		28046.94	27.2	0	5	5	1	200	3	2.00E+02	1.00E+06	1.00E+06	9.98E+02	1.00E+03	9.98E+02	trigger settings not right
2	19-Dec-20	10:15:38	10	155 Ta		28046.94	27.2	0	5	5	1	200	3	4.00E+02	1.00E+06	1.00E+06	1.00E+03	1.00E+03	2.00E+03	going to let the scope run to see
3	19-Dec-20	11:31:28	1	155 Ta		28046.94	27.2	0	5	5	1	200	3	200 to 400 to 5	1.00E+06	1.00E+06		1.00E+06	2.00E+03	1370000 first transient, 700mV positive going, found for trigger setting. Triggering on the leading edge of pulse on the low side, saw middle transient that way
4	19-Dec-20	11:44:11	1	155 Ta		28046.94	27.2	0	5.5	5.5	1	200	3	9.00E+02	1.00E+06	1.00E+06		1.00E+04	2.00E+03	counts for transients will be off, shark fin in middle of waveform, negative going. Find examples
5	19-Dec-20	11:54:05	1	140 Ta		25332.72	31.3	0	5.5	5.5	1	200	3	9.00E+02	1.00E+06	1.00E+06		1.00E+04	2.00E+03	realized that leading edge are added from rad, but exist randomly in operation
6	19-Dec-20	12:15:12	1	140 Ta		25332.72	31.3	0	5.5	5.5	1	200	3	9.00E+02	1.00E+06	1.00E+06		1.00E+04	2.00E+03	Transients captured
7	19-Dec-20	12:24:37	1	140 Ta		25332.72	31.3	0	5.5	5.5	1	200	3	9.00E+02	1.00E+06	1.00E+06		1.00E+04	2.00E+03	DC triggering mode. Peak on channel 1.5V
8	19-Dec-20	12:32:10	1	140 Ta		25332.72	31.3	0	5.5	5.5	1	200	3	9.00E+02	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
9	19-Dec-20	12:41:32	1	125 Ta		22618.5	37.6	0	5.5	5.5	1	200	3	9.00E+02	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
10	19-Dec-20	12:50:28	1	125 Ta		22618.5	37.6	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
11	19-Dec-20	12:57:51	1	125 Ta		22618.5	37.6	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
12	19-Dec-20	13:05:49	1	120 Ta		21713.76	41.8	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
13	19-Dec-20	13:16:48	1	200 Au		39393.4	25.7	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
14	19-Dec-20	13:23:57	1	200 Au		39393.4	25.7	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	might be able to make plot of transient sizes from DC plots over energy
15	19-Dec-20	13:30:22	1	200 Au		39393.4	25.7	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
16	19-Dec-20	13:36:51	1	180 Au		35454.06	30.1	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
17	19-Dec-20	13:43:30	1	140 Au		27575.38	33.4	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
18	19-Dec-20	13:50:03	1	140 Au		27575.38	33.4	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
19	19-Dec-20	14:00:07	1	140 Au		27575.38	33.4	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
20	19-Dec-20	14:06:11	1	140 Au		27575.38	33.4	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
21	19-Dec-20	14:12:22	1	140 Au		27575.38	33.4	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	
22	19-Dec-20	14:18:22	1	140 Au		27575.38	33.4	0	5.5	5.5	1	200	3	1.00E+03	1.00E+06	1.00E+06		1.00E+04	2.00E+03	

