

# Single Event Effects Testing of a Vertical Optocoupler with Unmodified Packaging

Landen D. Ryder, Thomas A. Carstens, Anthony M. Phan, Christina M. Seidlick, and Michael J. Campola

**Abstract**— Single event effects measurements were conducted on a ACPL-785E optocoupler at NASA Space Radiation Laboratory. Measurements with a periodic input signal show single event transients and a radiation-induced time delay of the output signal.

**Index Terms**— Single event effects (SEE), single event transient (SET), optocoupler, opto-isolator, heavy ion

## I. INTRODUCTION

Optocouplers, also known as opto-isolators or photocouplers, are a broad class of semiconductor devices that facilitate the transfer of an electrical signal from the input to the output side while providing electrical isolation between the two sides. Notionally, these devices consist of a light emitting diode (transceiver) and a photodiode or phototransistor (receiver), with the input signal being optical transmitted through a nonconductive polymer or airgap. Space and commercial electronic systems typically incorporate optocouplers in either 1) digital signal processing or 2) current signal transfer between subsystems. As optocouplers function as critical signal interconnects between subsystems or provide isolation for power systems, space-based applications require extensive device characterization to ensure that radiation-induced degradation will be properly mitigated within the system [1]-[2].

As optocouplers rely on the collection of optically generated carriers within a doped junction to transfer a signal between the isolated sides, the introduction of radiation-induced carriers from ionizing particles contributes to the output current signal. The resulting single event transient (SET) will propagate from the output of the device; standard mitigation techniques rely on the addition of filter circuitry to reduce the SET response of the optocoupler to below downstream system tolerances [3]. In many cases, optocouplers contain peripheral circuitry such as current amplifiers and signal converts that can result in additional single event effect (SEE) sensitivity.

SEE measurements using heavy ions were conducted on Broadcom's ACPL-785E opto-isolator at NASA Space Radiation Laboratory (NSRL) to examine its suitability for use in a space radiation environment. Due to the device construction and packaging, more common SEE testing facilities do not provide particle energies with sufficient range necessary for SET measurements on a functional device [4].

Landen D. Ryder, Thomas A. Carstens, and Michael J. Campola are with NASA Goddard Space Flight Center, Code 561, Greenbelt, MD 20771 USA (e-mails: [landen.d.ryder@nasa.gov](mailto:landen.d.ryder@nasa.gov), [thomas.a.carstens@nasa.gov](mailto:thomas.a.carstens@nasa.gov), and [michael.j.campola@nasa.gov](mailto:michael.j.campola@nasa.gov)).

Anthony M. Phan and Christina M. Seidlick are with SSAI Inc., Greenbelt, MD 20771 USA (emails: [anthony.m.phan@nasa.gov](mailto:anthony.m.phan@nasa.gov) and [christina.m.seidlick@nasa.gov](mailto:christina.m.seidlick@nasa.gov)).

While there were no observed destructive SEEs at the testing conditions outlined in this work, both SETs and a radiation-induced time delay between the input and the output signal were observed. To ensure reliable operation, systems that use this optocoupler may require additional mitigation strategies or design margins.

## II. DEVICE UNDER TEST

The physical layout of optocoupler are broadly classified as 1) a multilayer configuration with a light emitting diode inverted directly above the photodetector or 2) a single plane configuration that relies on optical coupling via reflections from the polymer. While the physical layout impacts device performance such as breakdown voltage or bandwidth, the layout can also significantly complicate SEE measurements and parts qualification. In the case of a single plane configuration, problematic packaging can be removed to provide direct access to the active areas of the devices for lower range particles while maintaining device operation. The material stack must remain largely uncompromised in multilayer configurations to maintain functionality, requiring that particles have sufficient

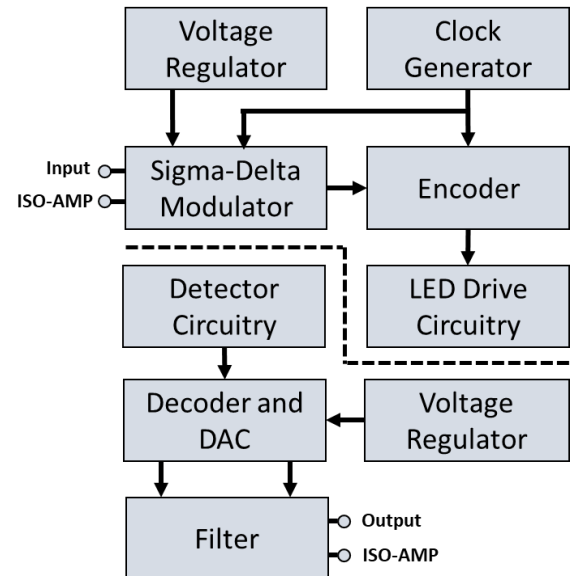


Fig. 1. Schematic representation of ACPL-785E optocoupler as outlined by the manufacturer [5]. Note that the dashed line corresponds to the isolation boundary between the input and output sides.

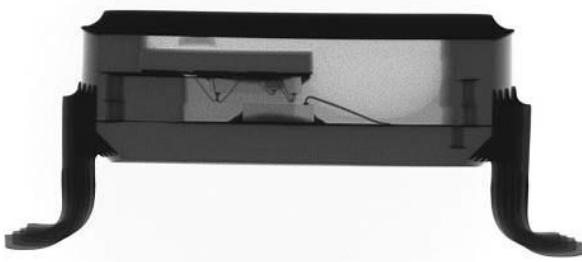


Fig. 2. X-ray image of the device to show the layers of the device packaging and dies.

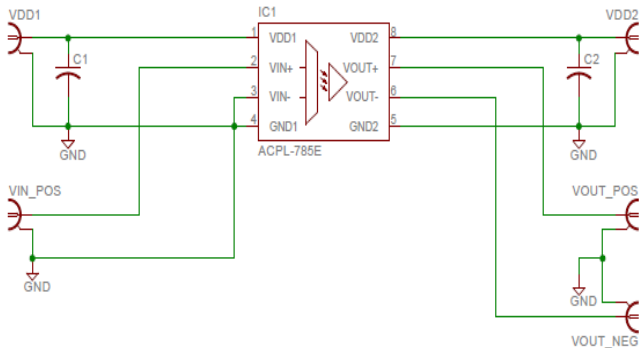


Fig. 3. Measurement circuit schematic for SEE characterization of the ACPL-785E optocoupler. Transient waveforms were captured on the two output channels VOUT\_POS and VOUT\_NEG.

TABLE I. TESTING LETs

| Particle Species | Particle Energy [GeV] | Estimated LET [MeV-cm <sup>2</sup> /mg] | Input Signal |
|------------------|-----------------------|-----------------------------------------|--------------|
| Tantalum         | 28.0                  | 27.2                                    | Square       |
| Tantalum         | 25.3                  | 31.3                                    | DC           |
| Tantalum         | 22.6                  | 37.6                                    | DC           |
| Tantalum         | 21.7                  | 41.8                                    | DC           |
| Gold             | 39.3                  | 25.7                                    | DC           |
| Gold             | 35.4                  | 30.1                                    | DC           |
| Gold             | 27.6                  | 33.4                                    | DC           |

energy to pass through multiple device substrates and packaging to deposit charge in the active areas of the device.

ACPL-785E is more complex than a typical multilayer optocoupler, utilizing additional circuit components to better represent the input signal that is transmitted to the output side of the device [5] (Fig. 1). While this additional functionality is valuable from a signal processing perspective, these additional circuit components introduce radiation vulnerabilities that must be interrogated. The packaging and construction of the device significantly attenuate the particle energy reaching the active area of the devices, precluding normal incidence testing at more common SEE facilities. Efforts to test at grazing angle to provide direct access to the active area were unsuccessful due to the device location relative to the packaging.

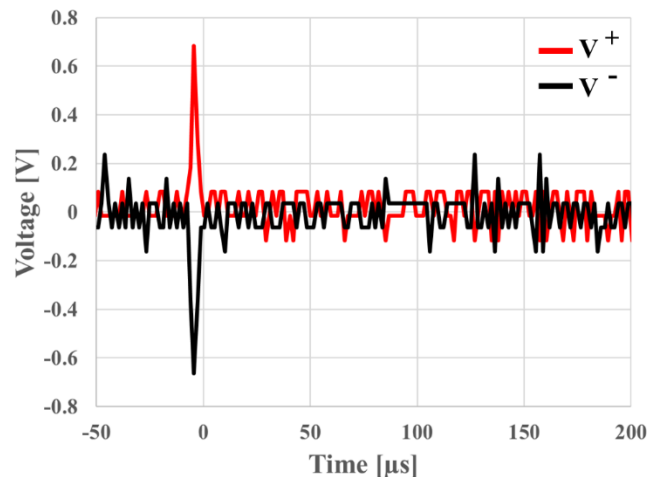


Fig. 4. Example narrow SETs observed at an LET of 30.1 MeV-cm<sup>2</sup>/mg. Note the symmetry of the transients.

To ensure that particles had sufficient energy and range to

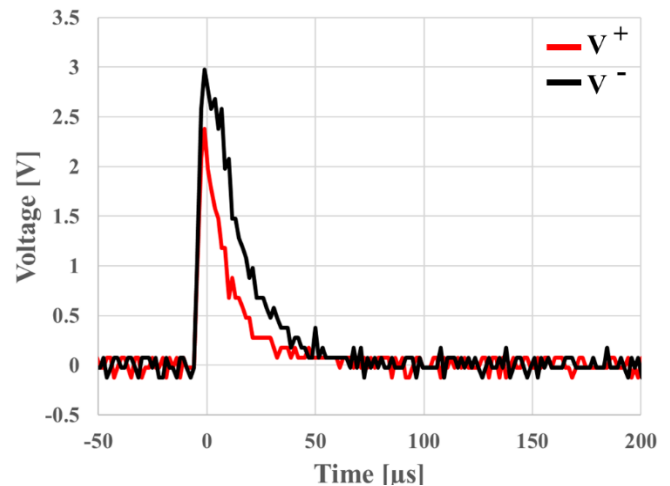


Fig. 5. Example large SETs observed at an LET of 30.1 MeV-cm<sup>2</sup>/mg. Note that both transients exhibit a positive polarity.

pass through the packaging and both dies at normal incidence, heavy ion testing was performed at NSRL. With manufacturer information in conjunction with measurements taken of the device (Fig. 2), the material stack that an incident particle will pass through can be estimated. For this test campaign multiple particle species and energies were used, and in conjunction with the material stack, the linear energy transfer (LET) of a particle in the active region of the devices can be estimated via SRIM [6]. The estimated LET used in this work are provided in Table 1.

A measurement circuit was fabricated to bias the devices for operation (5.5 V) with two channels each for the input/output signal of the device (Fig. 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. Both output channels were terminated with a 50  $\Omega$  resistance and measured with a 2 GHz oscilloscope to capture that output waveform for processing. As there is no bias tee, output waveforms will be a superposition of the response induced by the unperturbed input signal and the SET induced in the device. The average rise/fall time of the device is reported as 3.4  $\mu$ s, which is useful for relating transient

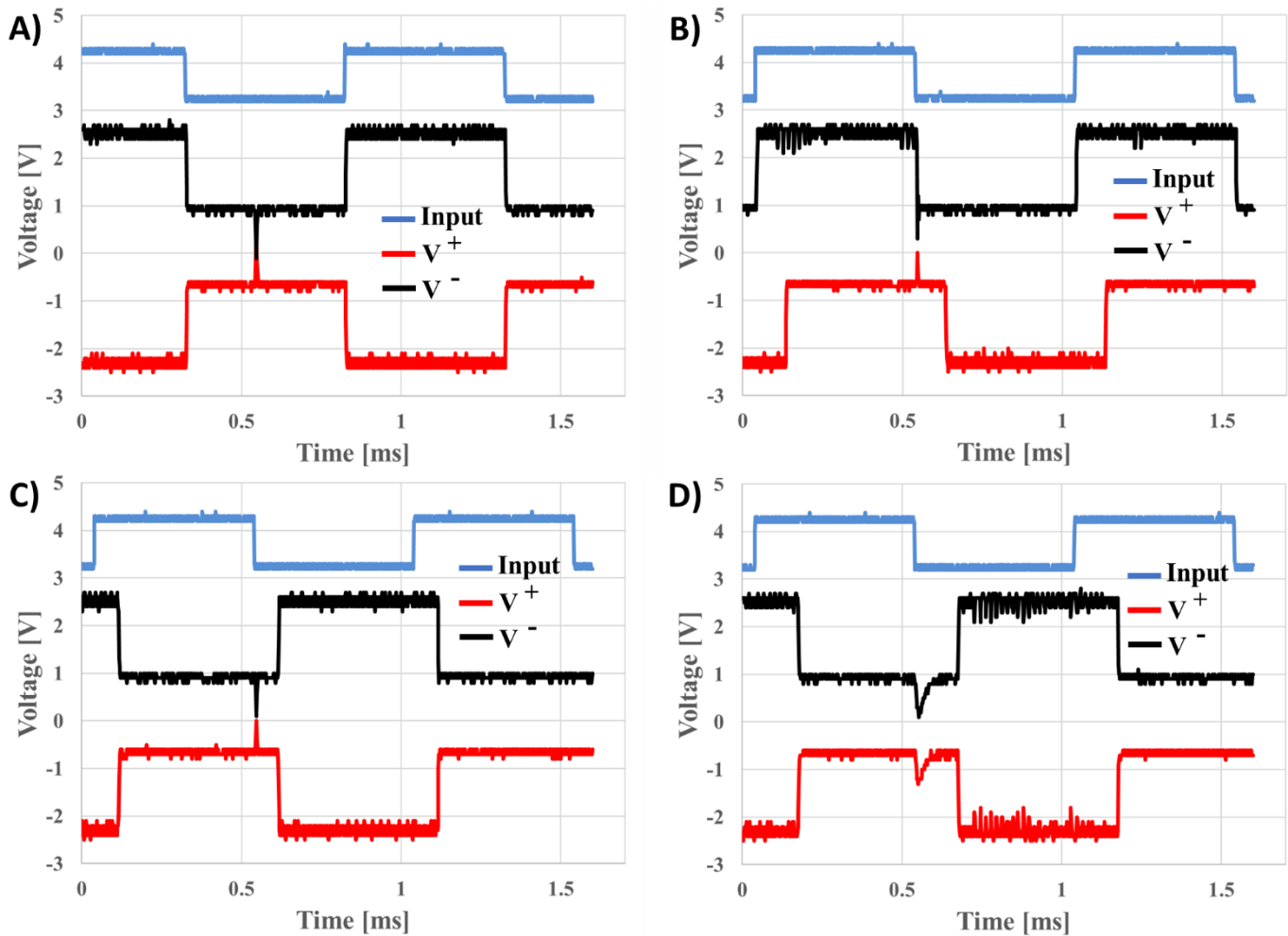


Fig. 6. Example output channels (red and black) measurements during heavy ion irradiation with an input square wave (blue). SETs are observed with the device response to the input signal with A) no radiation-induced delay, B) radiation-induced delay in one output channel, and C) radiation-induced delay 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.

duration to a time constant of the device under standard operation [5].

### III. RESULTS

Due to the subcomponents of this device, it would be expected that SETs measured at the output of the device will be a consequence of strike location. As the beam area is larger than that area of the device, it is not possible to directly identify the strike location in the device. Instead, the characteristics of the transients observed at the output channels can be used to localize the origin of the SET. For example, any SET originating in the input side of the device or at the photodiode will present as symmetric SETs (with opposite polarities) as the propagating SET will be superimposed with the photodiode response from the input signal.

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. 4. Due to the short duration and symmetry of the pulses, it is likely that these transients originate from collection of ion-induced carriers from the photodiode or

the input side of the device. The second category of transients (Fig. 5) is characterized by positive polarity transients with greater amplitude and duration than the previous category. As the output transients exhibit the same polarity, the strike location can be localized to circuitry downstream of the photodiode.

Alongside the expected SET response observed in the DC input signal response (Fig. 6A), SEE testing with the square wave input signal can present in a radiation-induced time delay in one or both output channels (Fig. 6B-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 mechanisms. 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. In the same way that the output SET can be localized within the circuit, the source of the delay can be isolated via the symmetry of the signal delay. 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. Signal delay in a single output channel is a consequence of an ion striking the timing components of the output side of the device while a delay appearing on both channels symmetrically is due to an ion strike on the timing components of the input side.

The ACPL-785E is designed with potential for analog input transient duration and amplitude more easily degrade the input signal integrity than digital signal. While in many cases the bandwidth of the optocoupler of the system can prevent SETs from propagating to the output, large amplitude SETs can potentially require additional transient mitigation techniques. The radiation-induced signal delay is likely to be the more concerning SEE for application designers. For example, a microcontroller using optocouplers to ensure electrical isolation from the systems it controls could result in desynchronization of the entire system. Application designers using optocouplers are likely acquainted with transient mitigation techniques such as filtering, but the radiation-induced signal delay observed in this component is something that is not seen in traditional optocouplers.

#### IV. CONCLUSIONS

Heavy ion SEE measurements were conducted on Broadcom's ACPL-785E optocoupler to screen for destructive SEEs (none observed) and examine SETs. 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 examined at the output of the device for both a DC and square wave input voltage signal. Additionally, the potential for significant radiation-induced time delay between an input square wave and resultant output waveform was observed. This signal delay is likely the consequence of an SEE occurring in the peripheral timing circuitry and represents an additional radiation vulnerability. Space-based applications including this component will be required to tolerate traditional SETs as well as the potential for signal delay at the interconnects.

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