*Radiation Report*

# *THVD9491-SEP Single-Event Effects (SEE) Radiation Report*


**ABSTRACT**

The purpose of this study is to characterize the single-event-effects (SEE) performance due to heavy-ion irradiation of the THVD9491-SEP, 1.2V to 5.5V octal bus transceiver. Heavy-ions with an $LET_{EFF}$ of 47.5MeV × $cm^2$ / mg were used to irradiate six production devices. Flux of approximately $10^5$ions/$cm^2$ × s and fluence of approximately $10^7$ions / $cm^2$ per run were used for the single-event latch-up (SEL) characterization and flux of approximately $10^4$ions / $cm^2$× s and fluence of approximately $10^6$ions / $cm^2$ per run were used for the single-event transients (SET) characterization. The results demonstrate that the THVD9491-SEP is SEL-free up to $LET_{EFF}$ = 47.5MeV × $cm^2$/ mg at 125°C. Additionally, the single-event transient (SET) performance for output voltage excursions ≥ |10%| from the nominal voltage are discussed.


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# 1 Overview

The THVD9491-SEP is a space enhanced, ±40V fault-protected full-duplex RS-422/RS-485 transceiver using a 1.65V to 5.5V logic supply for data and enable logic signals, and a 3V to 5.5V bus side supply. The device has a slew rate select function that enables the use at two maximum speeds based on the SLR pin setting.

See the THVD9491-SEP product page for more details. Overview Information lists device information.

**Table 1-1. Overview Information**

| Description | Device Information |
|---|---|
| TI Part Number | THVD9491-SEP |
| Orderable Part Number | THVD9491DTSEP |
| VID Number | V62/24626 |
| Device Function | Radiation Tolerant 3V to 5.5V RS-485 Transceiver with Flexible I/O Supply and IEC ESD Protection |
| Technology | LBC9 |
| Exposure Facility | K500 Cyclotron at Texas A&M University |
| Heavy Ion Fluence per Run | $1 \times 10^7$ ions / cm$^2$<br>And $1 \times 10^6$ ions / cm$^2$ |
| Irradiation Temperature | 125°C (for SEL testing)<br>and 25°C (for SET testing) |

# 2 Single-Event Effects (SEE) Mechanisms

The primary single-event effect (SEE) event of interest in the THVD9491-SEP is the destructive single-event latch-up. From a risk or impact perspective, the occurrence of an SEL is potentially the most destructive SEE event and the biggest concern for space applications. In mixed technologies such as the linear BiCMOS (LBC9) process used for THVD9491-SEP, the CMOS circuitry introduces a potential SEL susceptibility. SEL can occur if excess current injection caused by the passage of an energetic ion is high enough to trigger the formation of a parasitic cross-coupled PNP and NPN bipolar structure (formed between the p-substrate and n-well and n+ and p+ contacts). The parasitic bipolar structure initiated by a single-event creates a high-conductance path (inducing a steadystate current that is typically orders-of-magnitude higher than the normal operating current) between power and ground that persists (is latched) until power is removed or until the device is destroyed by the high-current state. The process modifications applied for SEL-mitigation were sufficient, as the THVD9491-SEP exhibited no SEL with heavy-ions up to an $LET_{EFF}$ of 47.5MeV × cm$^2$/mg at a fluence of $1 \times 10^7$ ions/cm$^2$ at a chip temperature of 125°C. The THVD9491-SEP was characterized for SET at a flux of approximately $10^4$ ions/cm$^2$ × s and a fluence of approximately $10^6$ ions/cm$^2$ with a die temperature of about 25°C. The device was characterized with two different bias schemes shown below. Under these bias conditions, all recorded VOUT voltage excursions self-recover with no external intervention.

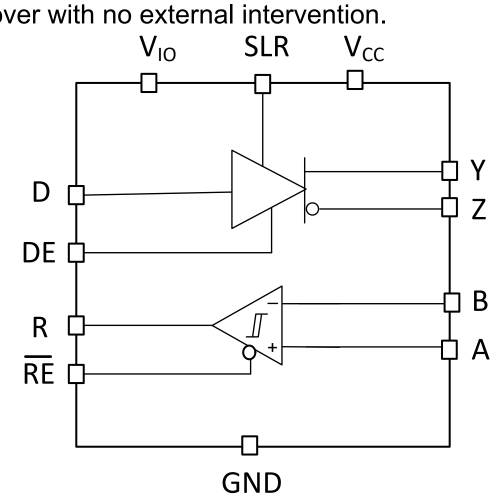


**Figure 2-1. Functional Block Diagram of the THVD9491-SEP**



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# 3 Test Device and Test Board Information

The THVD9491-SEP is a packaged 14-pin, SOIC plastic package as shown in the pinout diagram in Figure 3-2. Figure 3-3 shows the device with the package decapped to reveal the die for heavy ion testing. shows the evaluation board used for radiation testing. Figure 3-4 shows the bias diagram used for Single-Event Latch-up (SEL) testing. A thermal camera image used to verify accurate temperature recordings for SEL testing at 125°C.

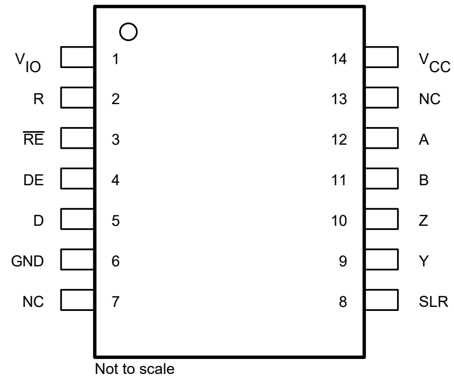


**Figure 3-1. THVD9491-SEP Pinout Diagram**

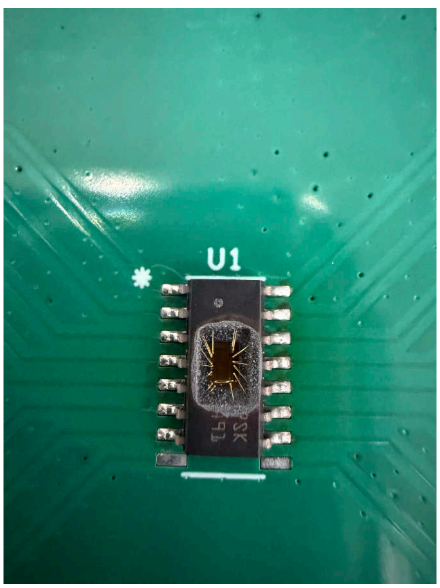


**Figure 3-2. THVD9491-SEP Pinout Diagram**

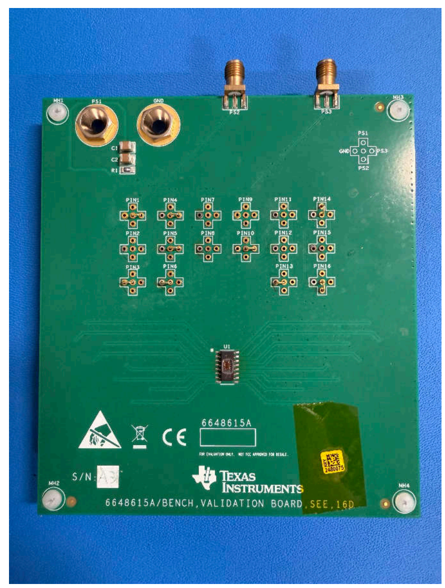


**Figure 3-3. THVD9491-SEP with Decapped Package**


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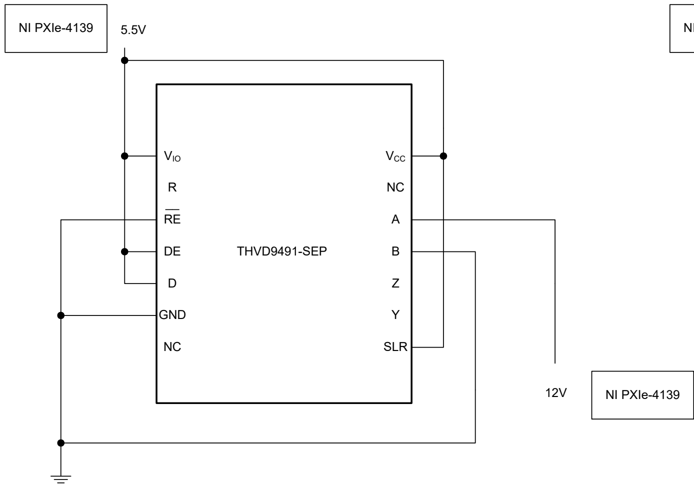


**Figure 3-4. THVD9491-SEP SEL Bias Diagram 1**

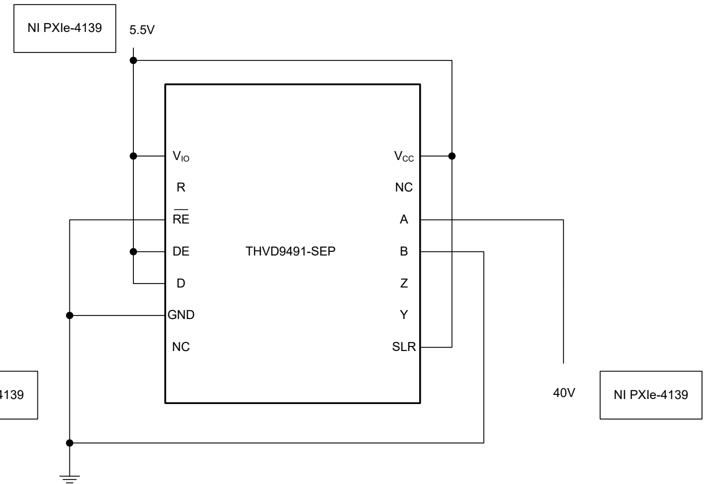


**Figure 3-5. THVD9491-SEP SEL Bias Diagram 2**

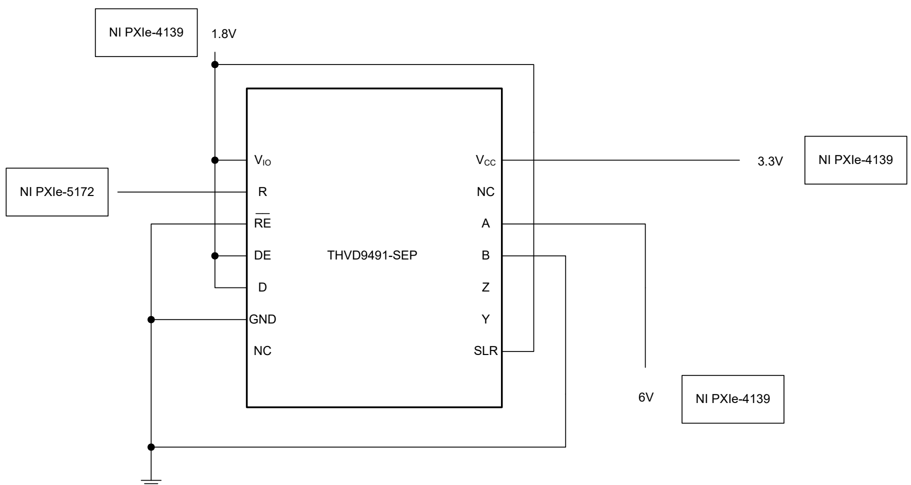


**Figure 3-6. THVD9491-SEP SET Bias Diagram 1**

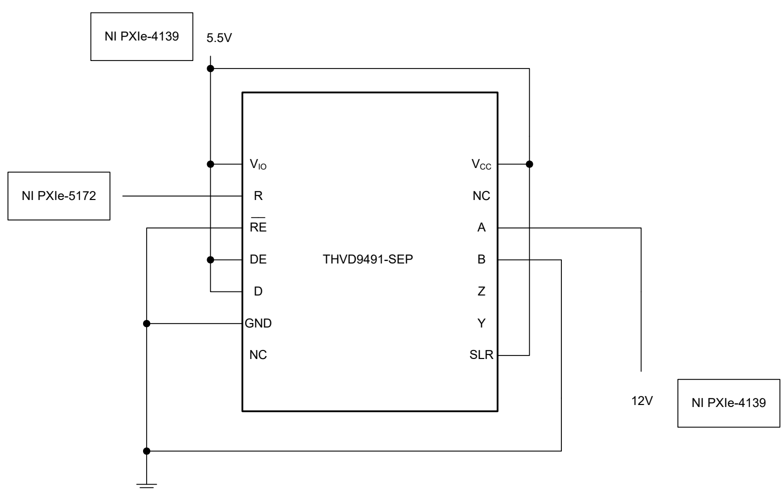


**Figure 3-7. THVD9491-SEP SET Bias Diagram 2**



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# 4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by the TAMU Cyclotron Radiation Effects Facility using a superconducting cyclotron and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity over a 1in diameter circular cross-sectional area for the in-air station. Uniformity is achieved by magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For this study, ion flux of $10^5$ions/cm$^2$ × s were used to provide heavy-ion fluences of approximately $10^7$ions/cm$^2$ for SEL testing and ion flux of $10^4$ions/cm$^2$ × s were used to provide heavy-ion fluences of approximately $10^6$ions/cm$^2$ for SET testing.

For the experiments conducted on this report, $^{109}$Ag ions at angle of incidence of 0° for an $LET_{EFF}$ of 47.5MeV × cm$^2$/mg were used. The total kinetic energy of $^{109}$Ag in the vacuum is 15MeV/nucleon. Ion uniformity for these experiments was between 88% and 93%.

Figure 4-1 shows one of the three THVD9491-SEP test board used for experiments at the Texas A&M University (TAMU) Cyclotron Radiation Effects Facility. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.

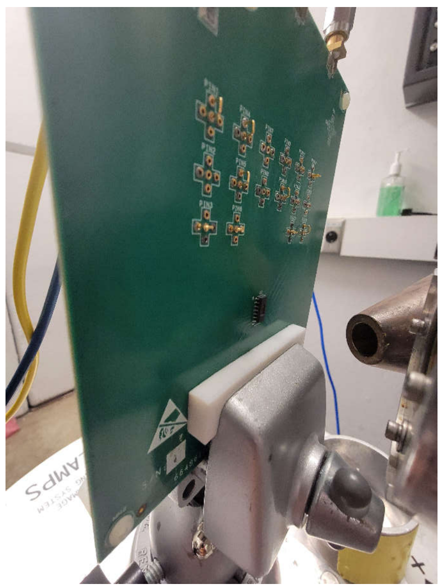

**Figure 4-1. THVD9491-SEP Evaluation Board at the TAMU K500 Cyclotron Facility**


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# 5 Results

## 5.1 SEL Results

During SEL characterization, the device was heated using forced hot air, maintaining device temperature at 125°C ± 5°C. A FLIR (FLIR ONE Pro LT) thermal camera was used to validate die temperature to make sure the device was being accurately heated. The species used for SEL testing was a Silver ($^{109}$Ag) ion at an energy of 15MeV/µ with an angle-of-incidence of 0° for an $LET_{EFF}$ of 47.5MeV-cm$^2$/mg. A fluence of approximately 1 × 10$^7$ions / cm$^2$ were used for the runs.

The three devices were powered up and exposed to the heavy-ions using the maximum recommended supply voltage of 5.5V with a National Instruments PXI Chassis PXIe-4139 and a second National Instruments PXI Chassis PXIe-4139 used for the different voltage levels on the A input pin. The run duration to achieve this fluence was approximately one and a half minutes. As listed in Table 5-1, no SEL events were observed during the six runs, which indicates that the THVD9491-SEP is SEL-free. Figure 5-1, Figure 5-2 show the plot of current versus time for runs one and four, respectively. The R output pin was also monitored during SEL.

**Table 5-1. Summary of THVD9491-SEP Test Conditions and Results**

| Run Number | Unit Number | Bias | Distance (mm) | Temperature (°C) | Ion | Angle | FLUX (ions × cm$^2$ / mg) | Fluence (Number of ions) | $LET_{EFF}$ (MeV × cm$^2$ / mg) | Did an SEL event occur? |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 40 | 124.1 | Ag | 0° | 1.00E + 05 | 1.00E + 07 | 47.5 | No |
| 2 | 1 | 2 | 40 | 124.1 | Ag | 0° | 1.00E + 05 | 1.00E + 07 | 47.5 | No |
| 3 | 2 | 1 | 40 | 123.7 | Ag | 0° | 1.00E + 05 | 1.00E + 07 | 47.5 | No |
| 4 | 2 | 2 | 40 | 123.7 | Ag | 0° | 1.00E + 05 | 1.00E + 07 | 47.5 | No |
| 5 | 3 | 1 | 40 | 123 | Ag | 0° | 1.00E + 05 | 1.00E + 07 | 47.5 | No |
| 6 | 3 | 2 | 40 | 123 | Ag | 0° | 1.00E + 05 | 1.00E + 07 | 47.5 | No |


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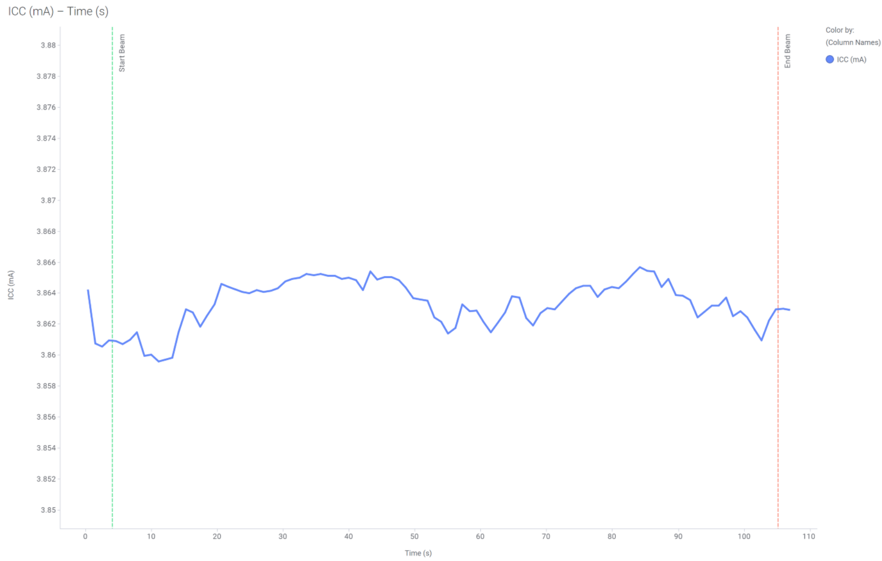


**Figure 5-1. Current versus Time for Run Number 1 of the THVD9491-SEP at T = 125°C**

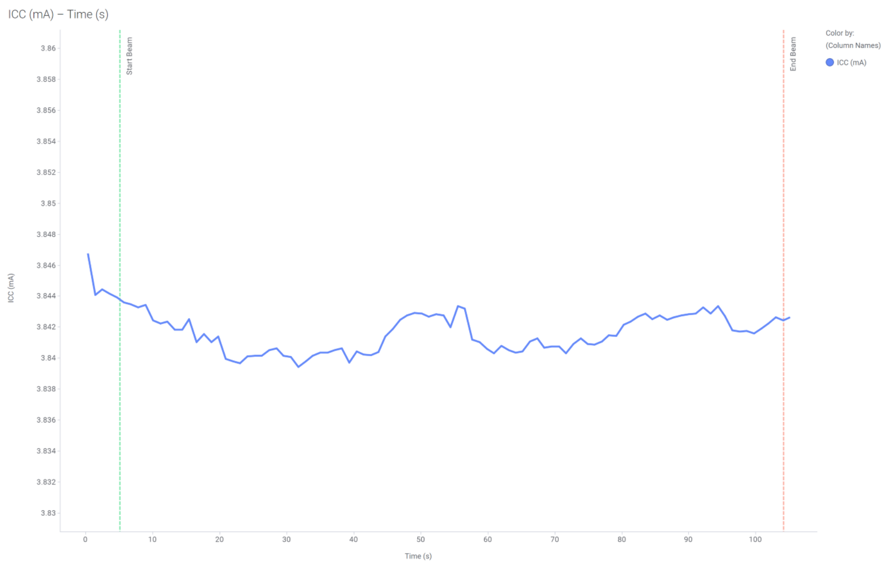


**Figure 5-2. Current versus Time for Run Number 4 of the THVD9491-SEP at T = 125°C**

No SEL events were observed, which indicates that the THVD9491-SEP is SEL-immune at $LET_{EFF}$ = 47.5MeV-$cm^2$ / mg and T = 125°C. Using the MFTF method described in Section 5.2, the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{SEL} \leq 1.23 \times 10^{-7}\ cm^2/\text{ device for } LET_{EFF} = 47.5\text{MeV-}cm^2 / \text{mg and T} = 125°\text{C}. \quad (1)$$


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## 5.2 Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations and simplified SEE cross-sections according to methods described in *Heavy Ion Orbital Environment Single-Event Effects Estimations*. A minimum shielding configuration of 100mils (2.54mm) of aluminum and worst-week solar activity is assumed. (This is similar to a 99% upper bound for the environment). Table 5-2 lists the event rate calculations using the 95% upper-bounds for the SEL. It is important to note that this number is for reference since no SEL events were observed.

**Table 5-2. SEL Event Rate Calculations for Worst-Week LEO and GEO Orbits**

| Orbit Type | Onset LET (MeV–cm$^2$ / mg) | CREME96 Integral Flux ( / day–cm$^2$) | $\sigma_{SAT}$ (cm$^2$) | Event Rate ( / day) | Event Rate (FIT) | MTBE (years) |
|---|---|---|---|---|---|---|
| LEO(ISS) | 47.5 | $6.40 \times 10^{-4}$ | $1.23 \times 10^{-7}$ | $7.87 \times 10^{-11}$ | $3.28 \times 10^{-3}$ | $3.48 \times 10^{7}$ |
| GEO | | $2.17 \times 10^{-3}$ | | $2.67 \times 10^{-10}$ | $1.11 \times 10^{-2}$ | $1.03 \times 10^{7}$ |

MTBE is the mean-time-between-events in years at the given event rates. These rates clearly demonstrate the SEE robustness of the THVD9491-SEP in two harshly conservative space environments. Customers using the THVD9491-SEP must only use the above estimations as a rough guide and TI recommends performing event rate calculations based on specific mission orbital and shielding parameters to determine if the product satisfies the reliability requirements for the specific mission.



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## 5.3 SET Results

SETs are defined as heavy-ion-induced transients upsets on $V_{OUT}$ of the THVD9491-SEP. The species used for the SET testing was a Silver (Ag), a Krypton (Kr) and an Argon (Ar) with an angle-of-incidence of 0° for an $LET_{EFF}$ of 47.5, 30.1 and 8.54MeV-cm$^2$/mg respectively. Flux of approximately $10^4$ions/cm$^2$ × s and a fluence of approximately $10^6$ions/cm$^2$ were used for all runs of SET testing. $V_{OUT}$ SETs were characterized using a window trigger of ±10% around the nominal output voltage. The devices were characterized in two different voltage cases. The first used a 3.3V VCC, 1.8V VIO and 6V A pin voltage. The second used a 5.5V VCC, 5.5V VIO and 12V A pin voltage. Both bias schemes used a NI PXIe-5172 to monitor the R pin as output. The scope triggering from $V_{OUT}$ was programmed to record 150 samples for both schemes with a constant sample rate of 100 mega-samples per second (MS/s) in case of an event. The scope was programmed to record 20% of the data before the trigger. Under heavy-ions, the THVD9491-SEP exhibits transient upsets that were fully recoverable without the need for external intervention. Test conditions and results are shown below in Table 5-3.

**Table 5-3. Summary of THVD9491-SEP Test Conditions and Results**

| Run Number | Unit Number | Ion | $LET_{EFF}$ (MeV × cm$^2$ / mg) | FLUX (ions /cm$^2$ × sec) | Fluence (ions / cm$^2$) | Bias # | Trigger Value (%) | $VOUT_{SET}$ (#) ≥10% [R Pin] |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Ag | 47.5 | 1.00E + 04 | 1.00E + 06 | 1 | 15 | 75 |
| 2 | 1 | Ag | 47.5 | 1.00E + 04 | 1.00E + 06 | 1 | 10 | 110 |
| 3 | 1 | Ag | 47.5 | 1.00E + 04 | 1.00E + 06 | 2 | 10 | 10 |
| 4 | 1 | Ag | 47.5 | 1.00E + 04 | 1.00E + 06 | 2 | 5 | 9 |
| 5 | 2 | Kr | 30.1 | 1.00E + 04 | 1.00E + 06 | 1 | 10 | 32 |
| 6 | 2 | Kr | 30.1 | 1.00E + 04 | 1.00E + 06 | 2 | 10 | 11 |
| 7 | 2 | Kr | 30.1 | 1.00E + 04 | 1.00E + 06 | 2 | 5 | 10 |
| 8 | 3 | Ar | 8.54 | 1.00E + 04 | 1.00E + 06 | 1 | 10 | 28 |
| 9 | 3 | Ar | 8.54 | 1.00E + 04 | 1.00E + 06 | 2 | 10 | 5 |
| 10 | 3 | Ar | 8.54 | 1.00E + 04 | 1.00E + 06 | 2 | 5 | 1 |


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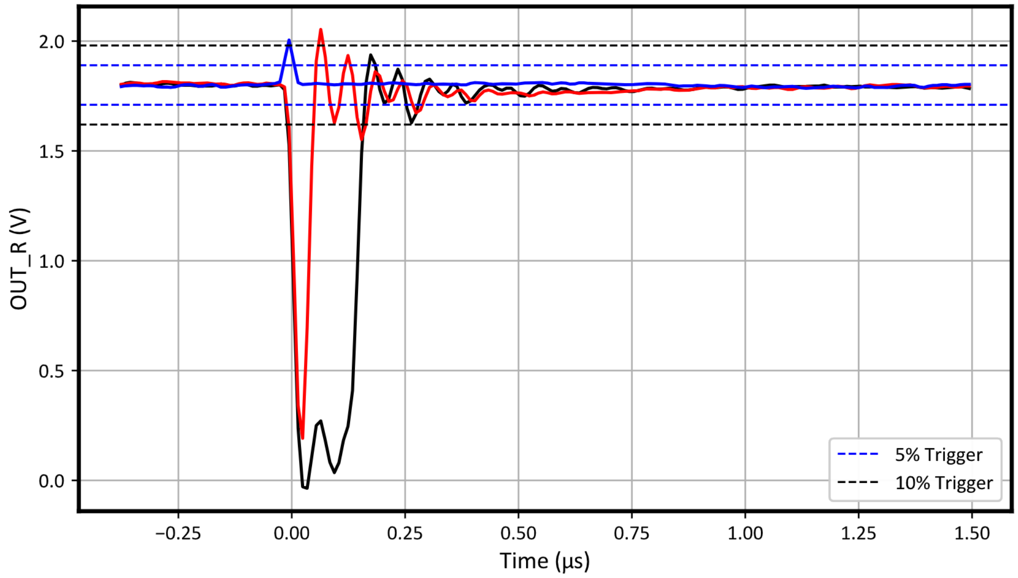


**Figure 5-3. Worst Case Transient Plot (Run 2 - R Pin)**

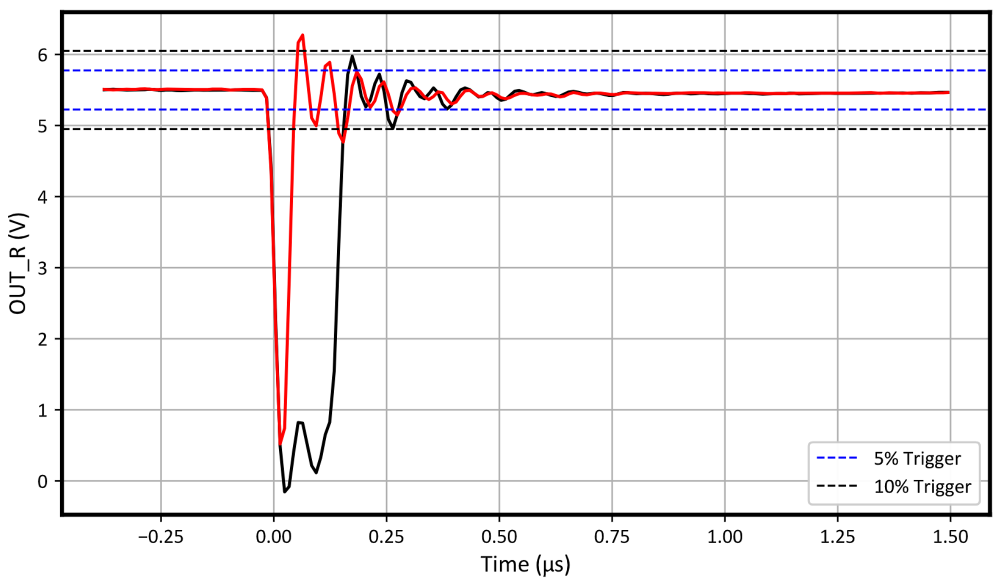


**Figure 5-4. Worst Case Transient Plot (Run 4 - R Pin)**

Using the MFTF method, the upper-bound cross section (using a 95% confidence level) is calculated for the different SETs as shown below.

**Table 5-4. Upper Bound Cross Section at 95% Confidence Interval**

| SET Type | Ion | Bias Scheme | Upsets (Number) | Upper Bound Cross Section ($cm^2$/device) |
|---|---|---|---|---|
| $VOUT_{SET}$ ≥ 10% | Ag | 1 | 110 | 1.326E - 04 |
| $VOUT_{SET}$ ≥ 10% | Ag | 2 | 10 | 1.839E - 05 |
| $VOUT_{SET}$ ≥ 10% | Kr | 1 | 32 | 4.517E - 05 |
| $VOUT_{SET}$ ≥ 10% | Kr | 2 | 11 | 1.968E - 05 |
| $VOUT_{SET}$ ≥ 10% | Ar | 1 | 28 | 4.047E - 05 |
| $VOUT_{SET}$ ≥ 10% | Ar | 2 | 5 | 1.167E - 05 |



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# 6 Summary

The purpose of this study was to characterize the effects of heavy-ion irradiation on the single-event latch-up (SEL) performance and single-event transients (SET) performance of the THVD9491-SEP, a radiation-tolerant 1.2V to 5.5V octal bus transceivers with tri-state outputs. Heavy-ions with an $LET_{EFF}$ of 47.5MeV × $cm^2$/mg were used for the SEE characterization. The SEE results demonstrated that the THVD9491-SEP is SEL-free up to $LET_{EFF}$ = 47.5MeV × $cm^2$/ mg and across the full electrical specifications. Transients at $LET_{EFF}$ = 47.5MeV × $cm^2$/ mg on $V_{OUT}$ are presented and discussed. CREME96-based worst-week event-rate calculations for LEO (ISS) and GEO orbits for the DSEE are presented for reference.


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## 7 References


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8. A. J. Tylka, W. F. Dietrich, and P. R. Boberg, "Probability distributions of high-energy solar-heavy-ion fluxes from IMP-8: 1973-1996", *IEEE Trans. on Nucl. Sci.,Vol. 44(6)*, Dec. 1997, pp. 2140-2149.


## 8 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from Revision * (October 2024) to Revision A (March 2025) | Page |
|---|---|
| • Updated the numbering format for tables, figures, and cross-references throughout the document | 1 |
| • Changed 43MeV to 47.5MeV throughout document | 1 |



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