Radiation Report
SLVK043–April 2019

TL7700-SEP Single-Event Latch-Up (SEL)

ABSTRACT

The purpose of this study was to characterize the effects of heavy-ion irradiation on the single-event latch-up (SEL) performance of the TL7700-SEP supply-voltage supervisor. Heavy-ions with an $\mathrm{LET}_{\mathrm{EFF}}$ of 43 MeV-cm^2/mg were used to irradiate the devices with a fluence of 1×10^7 ions/cm^2. The results demonstrate that the TL7700-SEP is SEL-free up to $\mathrm{LET}_{\mathrm{EFF}}$ = 43 MeV-cm^2/mg at 125°C.

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1 Overview

The TL7700-SEP is a bipolar integrated circuit designed for use as a reset controller in microcomputer and microprocessor systems. The SENSE voltage can be set to any value greater than 0.5 V using two external resistors. Circuit function is very stable with supply voltage in the 1.8-V to 40-V range. Minimum supply current allows use with ac line operation, portable battery operation, and automotive applications. The TL7700-SEP device is designed for operation from –55°C to 125°C.

www.ti.com/product/TL7700-SEP/technicaldocuments

Table 1. Overview Information(1)

DESCRIPTION	DEVICE INFORMATION
TI Part Number	TL7700-SEP
VID Number	V62/19602
Device Function	Radiation hardened supply-voltage supervisor in space enhanced plastic
Technology	JI1
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University
Heavy Ion Fluence per Run	$1 \times 10^6 – 1 \times 10^7$ ions/cm^2
Irradiation Temperature	125°C (for SEL testing)

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2 SEE Mechanisms

The primary single-event effect (SEE) events of interest in the TL7700-SEP are single-event latch-up (SEL). From a risk/impact point-of-view, the occurrence of an SEL is potentially the most destructive SEE event and the biggest concern for space applications. The JI1 was used for the TL7700-SEP. CMOS circuitry introduces a potential for SEL and SEB 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-sub and n-well and n+ and p+ contacts). The parasitic bipolar structure initiated by a single-event creates a high-conductance path (inducing a steady-state 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 TL7700-SEP exhibited no SEL with heavy-ions up to an LET_{EFF} of 43 MeV-cm^2/mg at a fluence of 10^7 ions/cm^2 and a chip temperature of 125°C.

This study was performed to evaluate the SEL effects with a bias voltage of 40 V on V_s supply voltage. Heavy ions with LET_{EFF} = 43 MeV-cm^2/mg were used to irradiate the devices. Flux of 10^5 ions/s-cm^2 and fluence of 10^7 ions/cm^2 were used during the exposure at 125°C temperature.

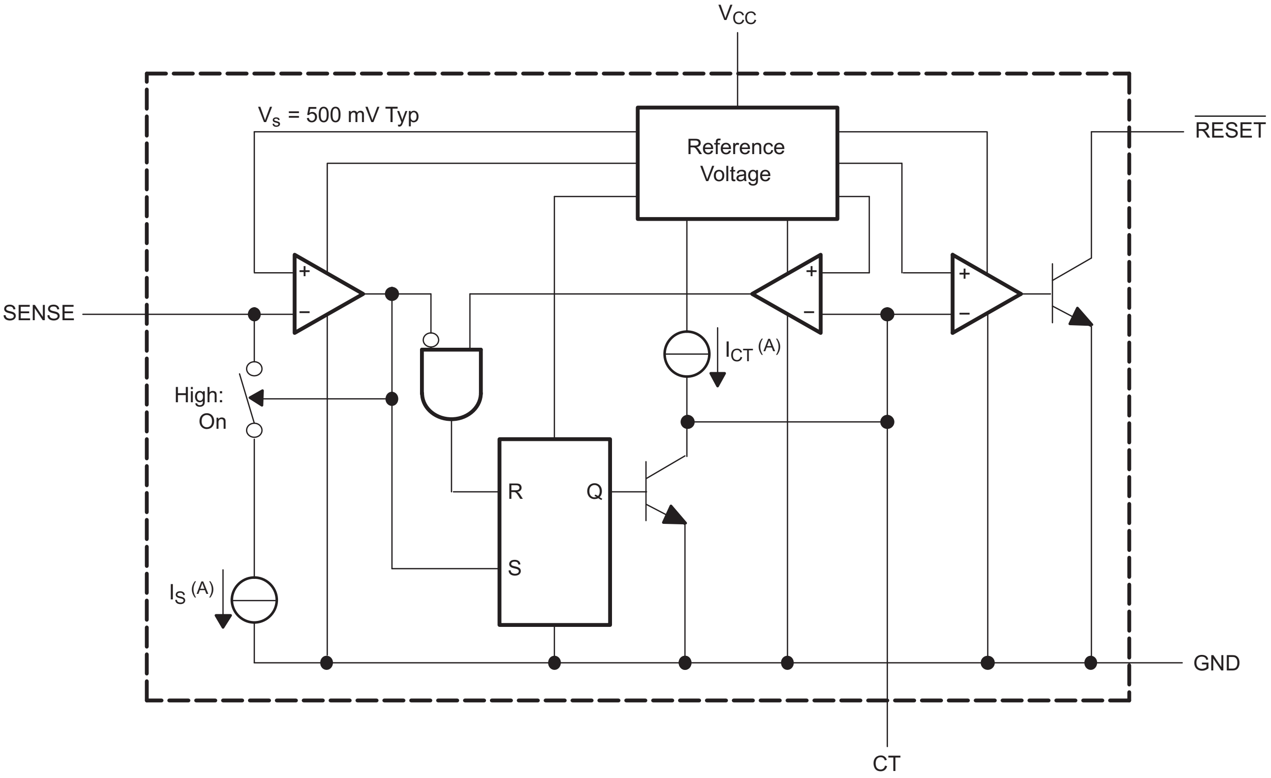

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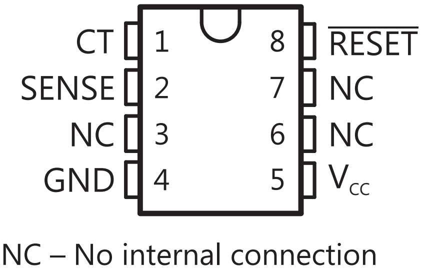
Figure 1. Functional Block Diagram of the TL7700-SEP

3 Test Device and Test Board Information

The TL7700-SEP is packaged in a 8-pin, TSSOP shown with pinout in Figure 2. The TL7700-SEP bias board used for the SEE characterization is shown in Figure 3 and bias diagram in Figure 4.



NOTE: The package was decap'ed to reveal the die face for all heavy ion testing.

Figure 2. TL7700-SEP Pinout Diagram

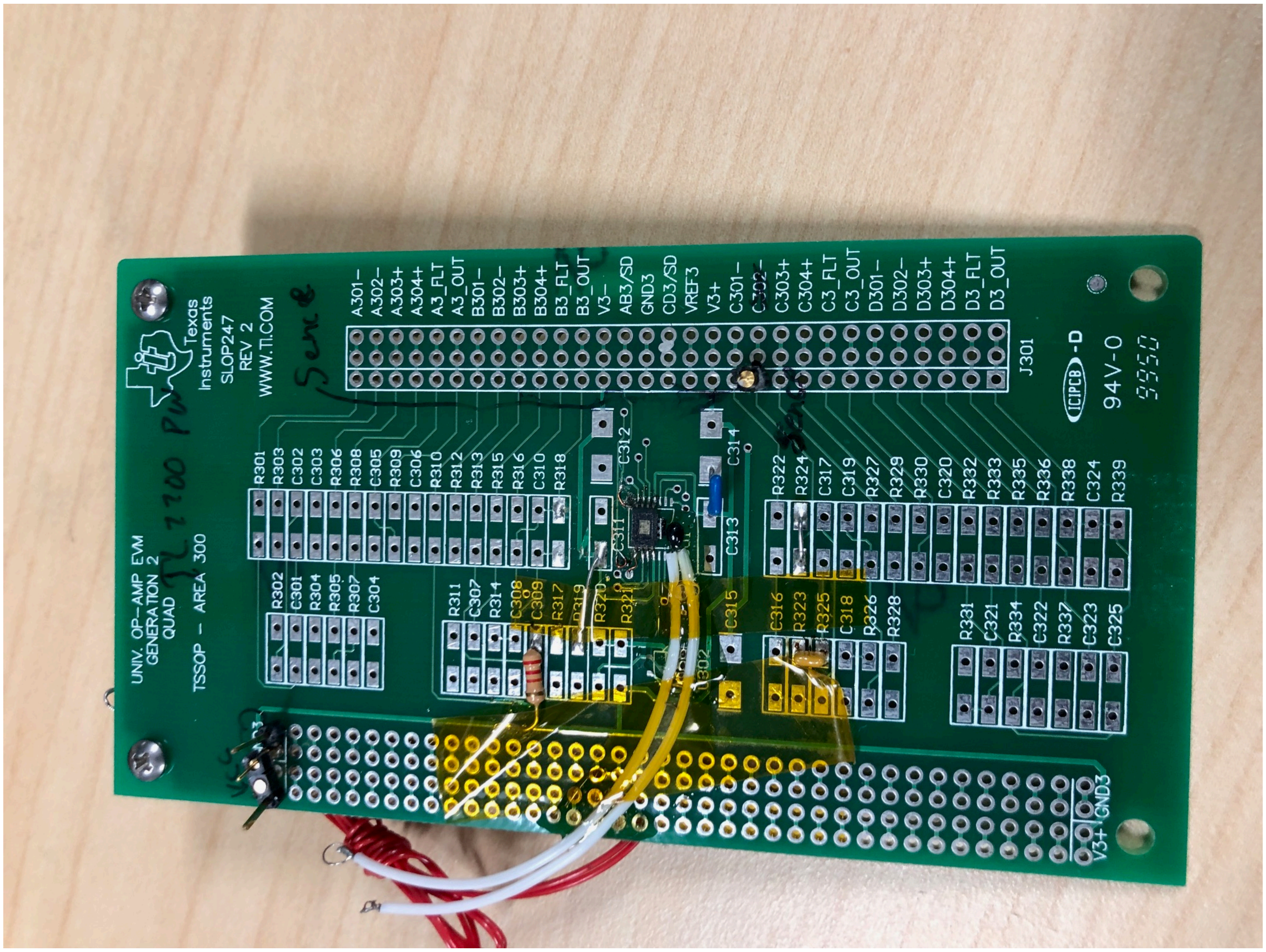


Figure 3. TL7700-SEP Bias Board Used for SEL Testing

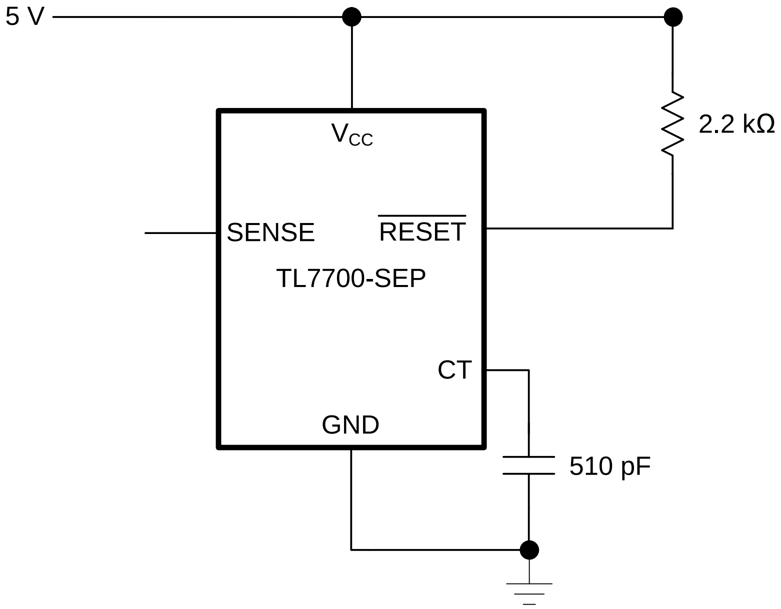


Figure 4. TL7700-SEP Bias Diagram

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 [3] using a superconducting cyclotron and advanced electron cyclotron resonance (ECR) ion source. Ion beams are delivered with high uniformity over a 1-in diameter circular cross sectional area for the in-air station. Uniformity is achieved by means of magnetic defocusing. The intensity of the beam is regulated over a broad range spanning several orders of magnitude. For the bulk of these studies, ion fluxes between 10^4 and 10^5 ions/s-cm^2 were used to provide heavy ion fluences between 10^6 and 10^7 ions/cm^2. For these experiments silver (Ag) ions were used. Ion beam uniformity for all tests was in the range of 91% to 98%.

5 Results

5.1 SEL Results

During SEL characterization, the device was heated using forced hot air, maintaining the IC temperature at 125°C. The temperature was monitored by means of a K-type thermocouple attached as close as possible to the IC. The species used for the SEL testing was a silver (^{47}Ag) ion with an angle-of-incidence of 0° for an LET_{EFF} = 43 MeV-cm^2/mg. The kinetic energy in the vacuum for this ion is 1.634 GeV (15-MeV/amu line). A flux of approximately 10^5 ions/cm^2-s and a fluence of approximately 10^7 ions were used for three runs. The V_s supply voltage is supplied externally on board at recommended maximum voltage setting of 40 V and the Vsense is set at 0.503 V. Run duration to achieve this fluence was approximately 2 minutes. No SEL events were observed during all four runs shown in Table 2. Figure 5 shows a plot of the current vs time.

Table 2. TL7700-SEP SEL Conditions Using ^{47}Ag at an Angle-of-Incidence of 0°

RUN #	DISTANCE (mm)	TEMPERATURE (°C)	ION	ANGLE	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	LET_{EFF} (MeV.cm^2/mg)
44	40	125	Ag	0°	1.00E+05	1.00E+07	43

No SEL events were observed, indicating that the TL7700-SEP is SEL-immune at LET_{EFF} = 43 MeV-cm^2/mg and T = 125°C. Using the MFTF method described in Appendix A and combining (or summing) the fluences of the two runs @ 125°C (1×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma\text{SEL} \leq 3.69 \times 10^{-7}$ cm^2 for LET_{EFF} = 43 MeV-cm^2/mg and T = 125°C.

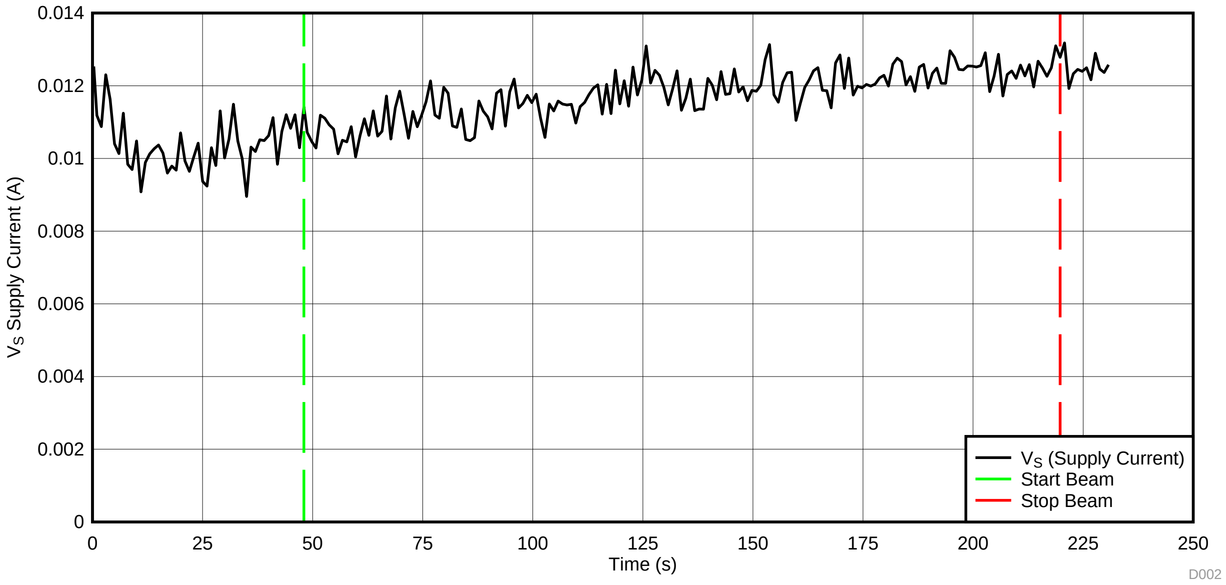


Figure 5. Current vs Time (I vs t) Data for V_s Current During SEL Run #44

6 Summary

Radiation effects of TL7700-SEP radiation hardened supply-voltage supervisor in space enhanced plastic was studied. This device passed total dose rate of up to 20 krad(Si) and is latch-up immune up to LET_{EFF} = 43 MeV-cm^2/mg and T = 125°C.

Appendix A

Confidence Interval Calculations

For conventional products where hundreds of failures are seen during a single exposure, one can determine the average failure rate of parts being tested in a heavy-ion beam as a function of fluence with high degree of certainty and reasonably tight standard deviation, and thus have a good deal of confidence that the calculated cross-section is accurate.

With radiation hardened parts however, determining the cross-section becomes more difficult since often few, or even, no failures are observed during an entire exposure. Determining the cross-section using an average failure rate with standard deviation is no longer a viable option, and the common practice of assuming a single error occurred at the conclusion of a null-result can end up in a greatly underestimated cross-section.

In cases where observed failures are rare or non-existent, the use of confidence intervals and the chi-squared distribution is indicated. The Chi-Squared distribution is particularly well-suited for the determination of a reliability level when the failures occur at a constant rate. In the case of SEE testing, where the ion events are random in time and position within the irradiation area, one expects a failure rate that is independent of time (presuming that parametric shifts induced by the total ionizing dose do not affect the failure rate), and thus the use of chi-squared statistical techniques is valid (since events are rare an exponential or Poisson distribution is usually used).

In a typical SEE experiment, the device-under-test (DUT) is exposed to a known, fixed fluence (ions/cm^2) while the DUT is monitored for failures. This is analogous to fixed-time reliability testing and, more specifically, time-terminated testing, where the reliability test is terminated after a fixed amount of time whether or not a failure has occurred (in the case of SEE tests fluence is substituted for time and hence it is a fixed fluence test [5]). Calculating a confidence interval specifically provides a range of values which is likely to contain the parameter of interest (the actual number of failures/fluence). Confidence intervals are constructed at a specific confidence level. For example, a 95% confidence level implies that if a given number of units were sampled numerous times and a confidence interval estimated for each test, the resulting set of confidence intervals would bracket the true population parameter in about 95% of the cases.

In order to estimate the cross-section from a null-result (no fails observed for a given fluence) with a confidence interval, we start with the standard reliability determination of lower-bound (minimum) mean-time-to-failure for fixed-time testing (an exponential distribution is assumed):

$$MTTF = \frac{2nT}{\chi^2_{2(d+1);\,100\left(1-\frac{\alpha}{2}\right)}} \tag{1}$$

Where *MTTF* is the minimum (lower-bound) mean-time-to-failure, *n* is the number of units tested (presuming each unit is tested under identical conditions) and *T*, is the test time, and χ^2 is the chi-square distribution evaluated at 100(1 – α / 2) confidence level and where *d* is the degrees-of-freedom (the number of failures observed). With slight modification for our purposes we invert the inequality and substitute *F* (fluence) in the place of *T*:

$$MFTF = \frac{2nF}{\chi^2_{2(d+1);\,100\left(1-\frac{\alpha}{2}\right)}} \tag{2}$$

Where now *MFTF* is mean-fluence-to-failure and *F* is the test fluence, and as before, χ^2 is the chi-square distribution evaluated at 100(1 – α / 2) confidence and where *d* is the degrees-of-freedom (the number of failures observed). The inverse relation between *MTTF* and failure rate is mirrored with the *MFTF*. Thus the upper-bound cross-section is obtained by inverting the *MFTF*:

$$\sigma = \frac{\chi^2_{2(d+1);\,100\left(1-\frac{\alpha}{2}\right)}}{2nF} \tag{3}$$

Assume that all tests are terminated at a total fluence of 10^6 ions/cm^2. Also assume there are a number of devices with very different performances that are tested under identical conditions. Assume a 95% confidence level ($\sigma = 0.05$). Note that as *d* increases from 0 events to 100 events the actual confidence interval becomes smaller, indicating that the range of values of the true value of the population parameter (in this case the cross-section) is approaching the mean value + 1 standard deviation. This makes sense when one considers that as more events are observed the statistics are improved such that uncertainty in the actual device performance is reduced.

Table 3. Experimental Example Calculation of MFTF and σ Using a 95% Confidence Interval(1)

Degrees-of-Freedom (d)	2(d + 1)	χ^2 @ 95%	Calculated Cross Section (cm^2)		
			Upper-Bound @ 95% Confidence	Mean	Average + Standard Deviation
0	2	7.38	3.69E–06	0.00E+00	0.00E+00
1	4	11.14	5.57E–06	1.00E–06	2.00E–06
2	6	14.45	7.22E–06	2.00E–06	3.41E–06
3	8	17.53	8.77E–06	3.00E–06	4.73E–06
4	10	20.48	1.02E–05	4.00E–06	6.00E–06
5	12	23.34	1.17E–05	5.00E–06	7.24E–06
10	22	36.78	1.84E–05	1.00E–05	1.32E–05
50	102	131.84	6.59E–05	5.00E–05	5.71E–05
100	202	243.25	1.22E–04	1.00E–04	1.10E–04

(1) Using a 95% confidence interval for several different observed results (d = 0, 1, 2,…100 observed events during fixed-fluence tests) assuming 10^6 ions/cm^2 for each test. Note that as the number of observed events increases the confidence interval approaches the mean.

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(2) G. Bruguier and J. M. Palau, "Single particle-induced latchup", *IEEE Trans. Nucl. Sci., Vol. 43(2)*, Mar. 1996, pp. 522-532.

(3) TAMU Radiation Effects Facility website. http://cyclotron.tamu.edu/ref/

(4) "The Stopping and Range of Ions in Matter" (SRIM) software simulation tools website. www.srim.org/index.htm#SRIMMENU

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