Laser-Induced and Heavy Ion-Induced Single Event Transient (SET) Sensitivity Measurements on LM139 Comparators

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Abstract

We have measured single event transients (SET) on a number of LM139 comparators with differing topologies. We report both pulsed laser-induced and heavy ion-induced measurements. We discuss the effects of different device topologies on SET sensitivity. Our results agree qualitatively with SPICE model calculations of LM139s by Johnston, et al.

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Introduction - Single event transients (SET) from analog devices have been the topic of a growing number of studies [1]-[9]. The temporal duration of these transients can be as long as several microseconds, and their amplitudes are often large enough to generate upsets at logic levels. Modeling these effects in analog devices has proven to be challenging due to the lack of information available from many of the device manufacturers. Most of the available data sheets for these devices are reduced to what is defined as a simplified or representative schematic for the device, and these often contain only the essential elements necessary to model the response of the device output as a function of input stimuli. While these models provide some insight into the behavior of a device, they generally do not contain all of the critical elements necessary to perform a complete transient evaluation.

Several studies in the past have included results from laser-induced SET measurements on analog devices in an attempt to better understand the origin and nature of SET in these devices [1]-[5]. These studies also showed that pulsed lasers could be used to reproduce the transient behavior that was observed during energetic particle testing. Several recent reports have also shown significant progress in applying the results from laser-based SET tests to modeling the response of these devices in a transient radiation environment [3], [5]. Accurately modeling the response of these devices requires the ability to excite each sensitive node on an individual basis, as well as determining the response of each node under different operating conditions. The use of a pulsed laser for these studies allows one to evaluate the SET sensitivity of these devices without cumulative effects such as total dose or displacement damage.

The 139 series of comparators utilizes Darlington configured differential amplifiers in the high-gain front end. These devices are known to be particularly susceptible to SET whenever the difference voltage between the two comparator inputs (ΔVin) is reduced below several hundred mV. These devices are also known to be susceptible to proton-induced SET [8].

Devices – We have performed measurements on three 139-class comparators: (a) PM139s from PMI, (b) HS1339-RHs from Intersil, and (c) LM139s from NSC. The PMI devices had a lot-date code of 1987, and the layout is much like that of the devices from NSC. The Intersil HS-139RH comparators are fabricated using a dielectrically isolated (DI), radiation-hardened silicon gate (RSG) process, incorporating only vertical NPN and PNP transistors [10]. The use of only vertical transistors was intended to reduce the enhanced low dose rate sensitivity (ELDRS) of these devices, but not necessarily their SET sensitivity. The physical layout of these devices is quite different from that of devices from the other manufacturers. These devices are attractive candidates for the laser-based SET measurements since they contain only vertical transistors that are dielectrically isolated from one another. The NSC devices included parts from their Scotland facility as well as newer devices fabricated at their Arlington, TX facility. In the presentation and the final paper, we will also provide results on these more recent parts. The results for these new LM139s from the TX facility will reflect any changes in SET sensitivity resulting from a 22% reduction in the die area. All devices were tested in the same circuit and under the same load conditions as shown in Fig. 3 from [2].

Laser Measurements - The laser system has been described in detail elsewhere [11], and we will only point out the important parameters. The laser wavelength was 600 nm, and has a penetration depth in silicon of approximately 1.8 µm at the 1/e point. The laser pulse width at the FWHM of intensity was 15 picoseconds, the spot size was 1.2 µm at the FWHM of intensity, and the laser repetition rate was 10 Hz for all of these measurements. We scanned all of the elements in one quadrant of each comparator, including the biasing circuitry at a laser pulse energy of ~40 pJ. This energy is comparable to an ion linear energy transfer (LET) value of 120 MeV/mg/cm^2 [11], [12]. In the presentation and the final paper, we will also present results of measurements at a laser wavelength of 815 nm.

Heavy Ion Measurements - Heavy ion measurements were performed at the Lawrence Berkley Laboratories (LBL) 88" cyclotron facility. Ions used for these studies were N, Ne, Ar, Cu, Kr and Xe, with corresponding LET values of 3.2, 5.6, 15, 30, 41, and 63 MeV/mg/cm^2. All of these ions have ranges between 45 and 55 µm in silicon. Additional heavy ion measurements will be preformed on the newer devices and the results will be included in the presentation and final paper.

Results - We have performed an extensive set of laser-induced SET measurements on the Intersil parts, and most of the data presented in this summary represents results from our measurements on these devices. However, we have also performed detailed bias dependence measurements in the input stages of comparators from all three manufacturers, and these results will be included in the presentation and final paper.

Fig. 1 shows a schematic for the HS-139RH comparator derived from a detailed inspection of the die. In the presentation and final paper, we will include similar diagrams for the other devices. Fig. 2 shows a photograph of the locations in the HS-139RH comparator that were found to be sensitive to laser-induced SET for ΔVin = ± 0.01V, and V_{dd} = 5.0V. In the presentation and final paper we will include photographs of the different comparator die identifying all of the locations within each comparator that are sensitive to laser-induced SET. Table 1 identifies the locations sensitive to laser-induced SET, the threshold energy for each location, and whether or not the SET sensitivity at that site was dependent on the value of ΔVin. Locations A through J in table 1 are sites that generated positive-going SET (ΔVin = -0.01V), while K through T were negative-going SET (ΔVin = +0.01V). We performed a simple test in order to determine the SET sensitivity of each location as a function of ΔVin. First, we set ΔVin to + or - 0.01V and positioned the laser at the most sensitive area of each location shown in Fig. 2. The laser pulse energy was then increased by a factor of two above the SET threshold for that site. The transient was then observed while ΔVin was gradually increased. If the transient rapidly narrowed and disappeared with increasing magnitude of ΔVin, the site was identified as being dependent on ΔVin. For all but six locations the SET were eliminated before ΔVin had reached a level of 1.0V. For locations H and R the transient duration was rapidly reduced to ~250 nsec before ΔVin had reached 0.5V, and these locations showed no dependence on ΔVin above 0.5V. The four locations that are identified in table 1 as having no dependence on ΔVin produced SET that were completely independent of the magnitude of ΔVin, and were 250 nsec or less. We were unable to obtain an accurate SET threshold at location F. Fig. 3 shows the SET sensitive cross-sections obtained for the Intersil devices during heavy ion-induced SET measurements under different input bias conditions. Note that there is nearly an order of magnitude reduction in the cross-section at or below a LET of 15 Mev/mg/cm^2 whenever ΔVin is increased from 0.2 to 0.3V. Also, of equal importance is the fact that the saturation cross section is the same at higher LET values for values of ΔVin up to 0.5V. Heavy ion measurements have been performed on the LM139s and will be performed on the new devices. These new results will be included in the presentation and the final paper. Fig. 4 shows the results from laser-induced SET measurements in the first stage of the input difference amplifier of three of the different comparator types for values of ΔVin between 0.01 and 1.00V (V_{dd} = 5V). These threshold values from these measurements were normalized at ΔVin = 0.5V. This shows the similarities between the responses of the three different devices. We will also present results from laser-induced SET measurements that show similar effects of ΔVin on the SET thresholds for the other devices. Fig. 5 shows the SET duration measured for transistor Q2 (PM139) as a function of laser pulse energy. We will include, in the presentation and final paper, similar results for the other devices. Fig. 6 shows the duration of several SET from transistor Q as a function of laser pulse energy. These results are from measurements on the HS-139 comparator. The value of ΔVin for these measurements was +0.1V, and the power supply voltage was 10.0V. In the presentation and final paper, we will present results showing the effect of ΔVin on the duration of the SET for the different device types.

Comparison with previous work – Many of the qualitative features observed in the response of these different comparators are consistent with the SPICE simulations and the experimental observations of Johnston and coworkers [3]. For example, results from the laser-induced SET measurements on our samples show a steady increase in threshold for ΔVin up to 200 mV and are then independent of bias to values of ΔVin greater than 0.5 V. This trend was modeled accurately in [3]. However, results from laser-induced SET measurements on all of our samples also show that the threshold increases rapidly whenever ΔVin approaches 1 V. All of the sensitive nodes in the input stage exhibit a similar dependence on ΔVin.

For the HS-139RH, we observed six locations (H, I, J, R, S, T) beyond the input stage where the SET were 200 nsec or less for ΔVin > 0.5V. The SET is slightly bias dependent for two of these locations (H, R) for values of ΔVin up to 0.5 V. The other four nodes show no dependence of SET threshold on bias. This is consistent with the results shown in Fig. 6 of [3].

The SET threshold for all other nodes shows a dependence on ΔVin similar to that displayed for transistor Q in Fig. 4. Thus, as ΔVin is increased, the cross section may be substantially reduced as node thresholds are driven above the laser pulse energy/LET and fewer nodes contribute to the SET response. At high values of ΔVin, the only nodes that may contribute to the cross section are those that exhibit little dependence on bias (H, I, J, R, S). Node T always has a threshold in excess of 40 pJ independent of bias conditions. Thus, its threshold is likely to be above the practical LETs available at most facilities for higher bias voltages. Consequently, it probably does not play a role in the SETs observed under particle-beam excitation.

Finally, at least for the HS-139RH, we do not observe any windows in SET sensitivity as reported by Buchner and coworkers for the LM119 comparator [5]. The SET windows reported for the LM-119 comparator were observed for excitation of the Q2 transistor in the input stage of that device. It is possible that the differences between the LM-119 and the HS-139RH are due to the dielectric isolation used in the HS-139RH. In the presentation and the final paper, we will report measurements on all of the nodes of the other 139-class devices to determine if such SET windows exist in these devices

Conclusions - We have evaluated the SET sensitivity of several similar comparators fabricated by PMI, Intersil and NSC. Results from laser-induced SET measurements show that neither circuit geometry, nor process significantly affects the SET sensitivity or the transient response of these devices. Instead, the results from laser-based measurements indicate that the SET sensitivity appears to be more dependent on the type of circuit chosen for the high gain input stages of these comparators. Our results do not show the window effect observed in [5], possibly a result of the different input stage configurations. They do however, provide strong support for the simulations and conclusions in [3]. These results show the potential of laser-induced SET testing for providing additional insight into the mechanisms responsible for SET in these and similar devices.

In the presentation and final paper, we will include results from additional laser-induced and heavy ion-induced SET measurements performed on the PMI devices and the newer NSC devices. We will also compare the results of these measurements with those obtained from the heavy ion-induced SET tests. The results from input bias dependence measurements will be presented for both, laser-induced and heavy ion-induced SET experiments.

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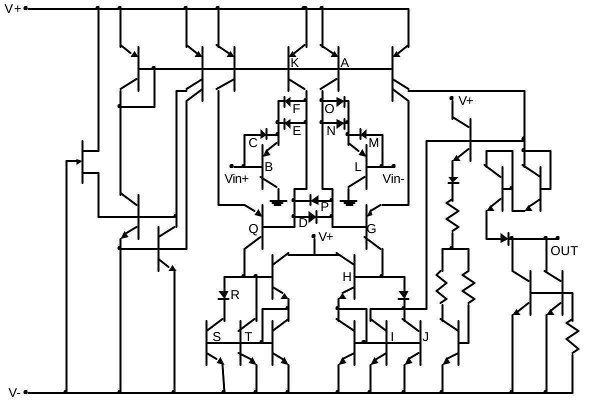

Fig. 1. Schematic for the HS-139RH.

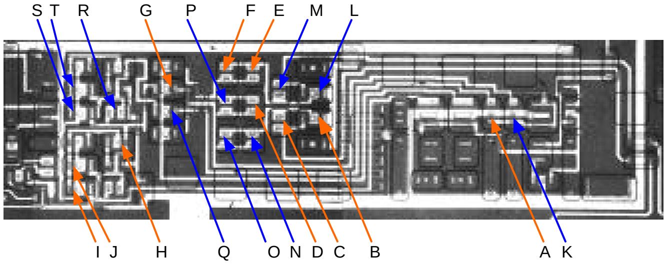

Fig. 2. Photograph of the HS-139RH showing all of the locations sensitive to laser-induced SET.

Table 1. Laser-induced SET thresholds and input bias dependence results for the HS-139RH comparator at ΔVin = 0.01V.

SET Loc.	E_p (pJ)	ΔVin Dep?	SET Loc.	E_p (pJ)	ΔVin Dep?
A	32	Yes	K	3.6	Yes
B	20.3	Yes	L	8.9	Yes
C	3.9	Yes	M	2.9	Yes
D	2.8	Yes	N	12.5	Yes
E	1.5	Yes	O	3.4	Yes
F	*	*	P	1.4	Yes
G	2.7	Yes	Q	1.0	Yes
H	17.7	Slight	R	8.8	Slight
I	17.7	No	S	7.0	No
J	17.7	No	T	40.3	No

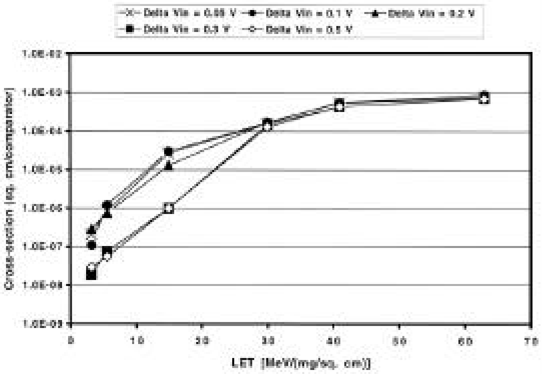

Fig. 3. Heavy ion SET test results for the HS-139RH (SN103) biased at 5 volts.

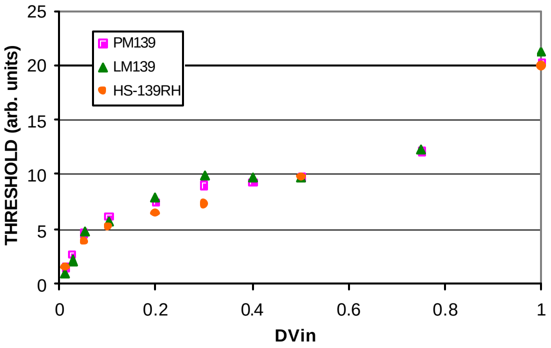

Fig. 4. Normalized thresholds for laser-induced SET measurements performed on the PM139, LM139 and HS-139 RH.

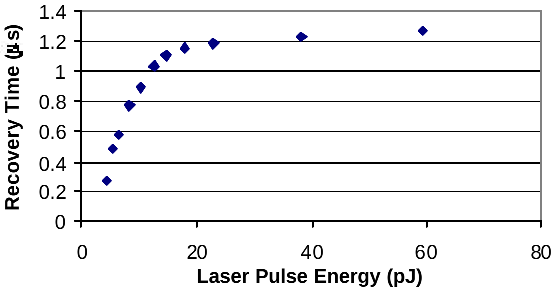

Fig. 5. SET duration from transistor Q2 in the PM139 at ΔVin = 0.05V (V_{dd} = 5V).

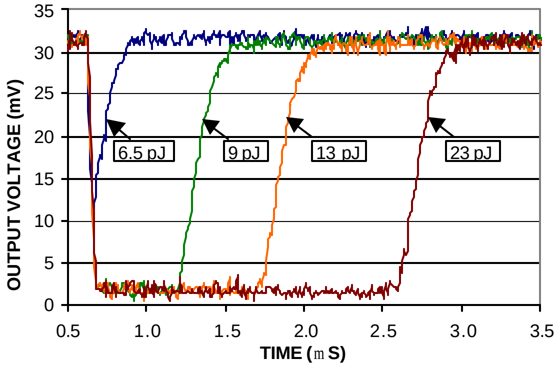

Fig. 6. Single event transient response as a function of laser pulse energy for transistor Q of the HS-139RH. Bias conditions were: V_{dd} = 10V, ΔVin = +0.1V.