Single Event Transient Characterization in the LM119 Voltage Comparator

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I. Abstract

SETs generated by pulsed-laser light, heavy ions and circuit simulators in the LM119 fast voltage comparator are compared under various operating conditions. The use of the pulsed laser for hardness assurance is also described.

II. Introduction

There is currently great interest in studying single event transients (SETs) in linear bipolar circuits. [1,2,3,4,5,6,8,11] This is motivated by the desire to limit the number of operating conditions the parts must be subjected to during testing in order to fully characterize their SET response. Linear circuits can be operated under many different conditions of supply and input voltages as well as output loading, all of which have a major impact on the amplitude and duration of the single-event transients.

It is becoming clear that some minimum set of heavy-ion tests will have to be conducted to base-line the data. These test results can then be augmented by computer modeling using circuit simulator programs to determine the SET sensitivity under conditions not tested with heavy ions. However, before that can be done, it is essential to validate the model by comparing SETs generated by the model with those generated by a pulsed laser. The pulsed laser is useful because it can deposit controlled amounts of charge at known transistor junctions (not covered with metal) under any operating condition.[7,9] It is also less expensive and more accessible than a microbeam.

In this paper we will present results comparing SETs generated in the LM119 voltage comparator using pulsed laser light and heavy ions with those obtained from computer modeling using SPICE simulations. The excellent agreement is predicated on the use of a sufficiently short current pulse for charge injection in the SPICE circuit model, and careful attention to the exact loading conditions, such as parasitic output capacitance and resistance. Using a probe with low parasitic capacitance is essential for measuring the response of the LM119 circuit itself to injected charge, whether by heavy ions or by laser light. Once the circuit model has been validated, SETs can be studied under a variety of operating conditions without the need for additional accelerator data.

To illustrate the use of the pulsed laser as a tool for SET hardness assurance in linear bipolar circuits, we have used the pulsed laser to investigate the variation of the SET threshold for LM119 circuits. We have compared variability of parts intra-lot and lot-to-lot and found a slightly greater difference in lot-to-lot than intra-lot.

III. Results

a) Modeling Results

A considerable effort has recently been devoted to modeling SETs in relatively slow circuits, such as the LM124 operational amplifier and the LM111 voltage comparator, using the circuit simulator program SPICE.[3,4,5] Confidence in the modeling results relies on use of the pulsed laser to identify the SET sensitive junctions, and on the comparisons of SETs generated by the pulsed laser with the modeling results. When testing faster devices, such as the LM119, there are important differences that must be considered, such as the pulse duration and output loading.

When using circuit simulator programs, such as SPICE, for modeling SETs in linear circuits, fidelity of the model requires that short duration current pulses (~100 ns) be used to inject charge at sensitive nodes. They were much shorter than the pulses used for modeling SETs in the LM124 and LM111.

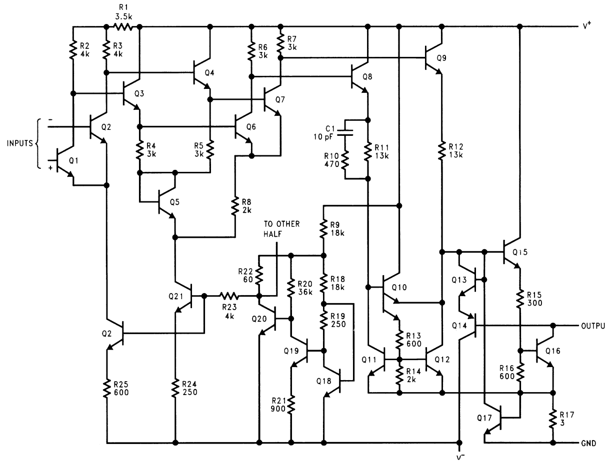

Fig. 1. LM119 circuit diagram. The output node is the open collector of Q16 which is connected to a 5 V supply through a 1.7 KΩ resistor. SETs are captured with a low capacitance (11 pF) probe.

The conditions under which the SETs are captured must be accurately known to make comparisons between modeling and experimental results possible. This applies particularly to output loading that can affect both the size and shape of a SET. Unfortunately, many reports in the literature do not include details about output loading. We illustrate this point with actual data.

The use of much shorter pulses together with accurate knowledge of the loading and operating conditions for the LM119 result in good agreement between SETs obtained by the laser and from SPICE modeling.

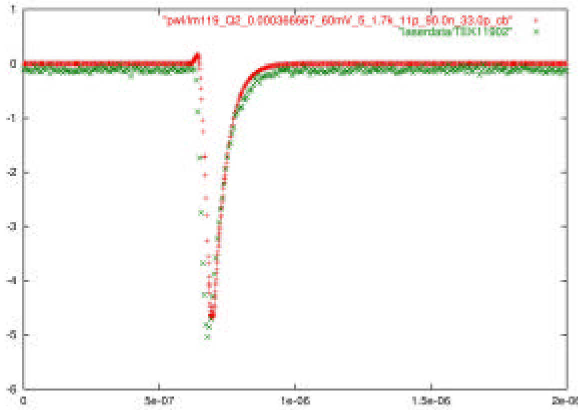

Fig. 2. SETs obtained from pulsed laser and SPICE modeling. Operating conditions were V_{dd} = 5V, V_{ss} = -5V, ΔV_{input} = 60mV, R_{pullup} = 1.7 KΩ, $C_{parasitic}$ = 11 pF.

Fig. 2 shows traces obtained by irradiating transistor Q2 with the laser and by injecting charge at the C/B junction in the circuit simulator model. The amount of injected charge used in the SPICE model was adjusted until good agreement was obtained. The exact experimental conditions are noted below the figure. The same level of agreement was found for SETs generated in other transistors. In the final paper the relative sensitivities of all the transistors will be listed and compared with those obtained using the pulsed laser.

b) Pulsed Laser Results

As already pointed out, the exact conditions under which SET measurements are taken must be specified. In addition, because the LM119 is a fast circuit, low-capacitance probes must be used to capture the SET's high-frequency components. Two transients obtained under different loading conditions are compared. Laser light was focused on transistor Q12 and the part's output pin was connected to an oscilloscope first with a probe and then with a coaxial cable. Fig. 3 shows the transient obtained with the low-capacitance probe. The amplitude is 3.75V and the width is less than 100 ns.

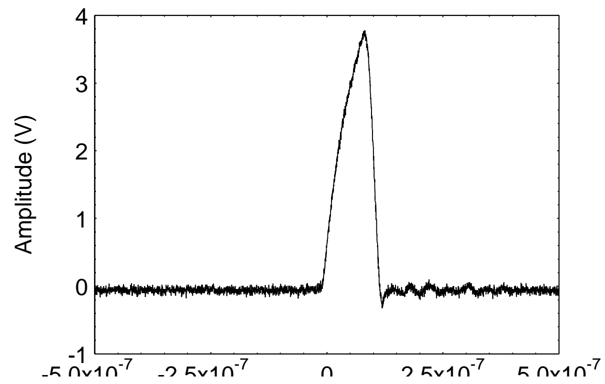

Fig. 3. SET from transistor Q1 with V_{dd}= 5V, V_{ss}= -5V, ΔV= -90 mV, R_{pullup} = 1.7 KΩ, $C_{parasitic}$ = 11 pF, V_{output} = 5V.

Fig. 4 shows a transient captured with the part connected to the oscilloscope via a coaxial cable.

In this case the amplitude is only 1.26 V and the pulse is considerably wider. There also appears to be a negative component. These effects have important ramifications when testing parts in a vacuum chamber because both vacuum feedthroughs and long cables from the vacuum chamber to a storage oscilloscope will affect the SET amplitude and duration. An example of this will be shown in the next section.

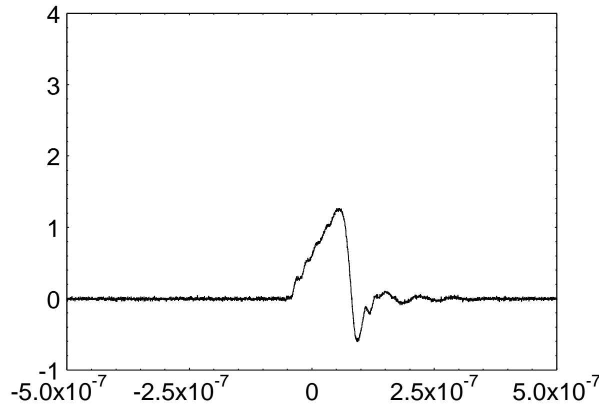

Fig. 4. SET from transistor Q1 with Vdd = 5V, Vss = -5V, ΔV = -90 mV, R = 1.7 KΩ, 2' foot cable, V_{out} = 5V.

We used the LM119 to assess whether a pulsed laser can be used for doing hardness assurance measurements for linear bipolars. Recently, National Semiconductor, the manufacturer of the LM119 parts, changed the process from 4" to 6" wafers. Even though the circuit topology was not changed, there were bound to be unavoidable changes in the processing associated with the use of new equipment. Process changes could likely have an effect on the SET sensitivity if, for instance, thinner epitaxial layers were used.

The light was focused on the same location (Q11) for all parts from both the 4" and 6" wafer lots. The average SET amplitude for fixed laser energy for parts from the 6" wafer was 4.82 V with a standard deviation of 0.25 V. For the 4" wafer, the average SET amplitude was 4.37 V with a standard deviation of 0.14 V. Therefore, it appears that the parts from the 6" wafer are slightly more sensitive than from the 4" wafer. These measurements will be augmented by measurements from other transistors.

c) Heavy Ions

We have previously reported on the results of a comprehensive study of SETs in the LM119 using a pulsed laser.[10,11] The SETs were studied under a wide variety of conditions to assist circuit simulators in verifying their transistor models. During the course of that investigation, we found that the SET sensitivity of Q2 (an input transistor) depended on the differential input voltage. The behavior was unusual in that Q2 was most sensitive at low and high differential input voltages, behavior confirmed by modeling.[11] The data of Koga et al did not show this because they did not go to sufficiently low or high differential input voltages.[1] We also found that less laser energy was needed to generate SETs for $\Delta V_{in} < 0V$ than for $\Delta V_{in} > 0V$, that large areas between transistors were sensitive, and more transistors were SET sensitive, suggesting the possibility of a much greater heavy-ion cross-section.

Heavy-ion testing of the LM119 was carried out at Brookhaven National Laboratory. We found that the cross-section for $\Delta V > 0$ V was $9.45x10^{-5}$ cm^2, which is more than an order of magnitude smaller than for $\Delta V > 0$, which was $1.11x10^{-3}$cm^2. This confirms the predictions made with pulsed laser light. more than an order of magnitude larger, confirming the laser predictions. The dependence on differential input voltage was also measured with heavy ions. Table 1 shows the results.

Table I. Measured Cross-Section as a function of differential input voltage for Cl ions with an LET of 11.4 MeV.cm^2/mg and V_{trig} = 4.7V.

ΔV_{in} (Volts)	LET (MeV.cm^2/mg)	σ (cm^2)
0.06	11.4	1.75E-5 ± 0.13E-5
2.5	11.4	1.72E-5± 0.13E-5
4.5	11.4	1.74E-5± 0.2E-5

There is no statistical difference between the numbers, suggesting that the input transistor Q2 does not contribute significantly to the SET cross-section. This result is consistent with the higher threshold observed in the pulsed laser measurements. In this case the laser results may not be indicative of the true threshold because bipolar circuits have numerous junctions (c/b, b/e and c/s) at different depths. The pulsed laser light

has a penetration depth (1/e of its value at the surface) of 2 μm so that lower junctions that are more sensitive than junctions closer to the surface will, nevertheless, appear less sensitive because less light reaches the deeper junctions. The heavy ion and pulsed laser data confirm and yield insight into why no dependence on differential input voltage was observed by Koga et al. [2]

Finally, we measured heavy-ion induced transients in the LM119 for ΔVin < 0V without a probe. Fig. 5 shows a typical SET obtained. The SETs are very similar to those obtained with the laser using a cable instead of a probe, except that the accelerator data are somewhat noisier. Comparison of Fig. 3, 4 and 5 illustrates the distortion of the SET introduced by both the connector in the vacuum feedthrough and the cable from the vacuum port to the oscilloscope. This distortion can be avoided by using drivers between the part and the oscilloscope. Note, that if the oscilloscope trigger level had been set to 1 V, no transients would have been recorded, resulting in an erroneous conclusion about the SET sensitivity of the LM119.

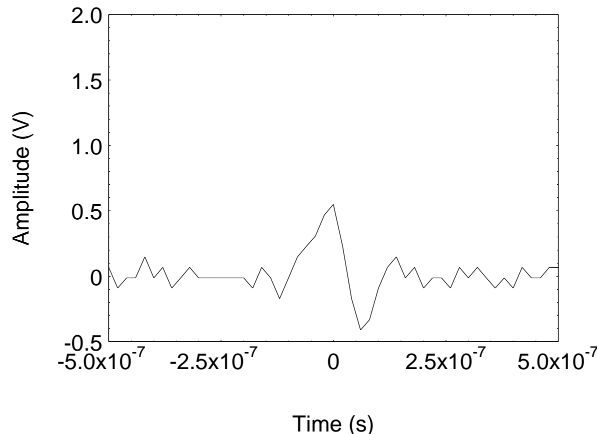

Fig. 5. SET transient captured without a probe. V_{dd} = 5V, V_{ss}= -5V, R_{pullup} = 1.7 KΩ, 6' BNC cable with vacuum feedthrough, ΔV_{in}= -0.2V, V_{pullup}=5V, Cl ions with LET = 59.74 MeV.cm^2/mg.

IV. Conclusions

In this paper we have discussed a number of issues that bear on SET testing of fast linear bipolar circuits. We have pointed out the necessity of using injection currents in the modeling approach that are faster than the response time of the circuit to avoid obtaining erroneous results. The output loading conditions play a significant role in shaping the SET and will affect the cross-section measured with heavy ions and any comparisons between SETs generated by laser light and modeling. We have confirmed predictions made with a pulsed laser that the part is significantly more sensitive for negative differential input voltages and we have explained why the cross-section does not appear to depend on differential input voltage. Finally, we have used the pulsed laser to measure a small difference in the SET sensitivities of parts from 4" and 6" wafer lots.

V. References

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