Characterization of SET Response of the LM124A, the LM111, and the LM6144

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Abstract—We present a paper that characterizes the Single Event Transient response of the LM124, LM111, and LM6144 in a heavy ion environment. In the paper both the test methods used and the data are presented.

I. INTRODUCTION

In this work the Single Event Transient (SET) response of the LM124A operational amplifier, LM6144 operational amplifier and LM111 voltage reference will be investigated, characterizing the cross-section as well as the SET pulse duration and amplitude. This work is intended to be a follow up of previous experiments, and is meant to not only complete the data for the LM111 and LM124 but to add the LM6144 to the existing body of ASET data [1]. Further investigation shows that the transient pulses exhibited variations in pulse shape from event to event in the LM124A and the LM6144. These variations were found to fall into three distinct classes in the LM124 and four distinct classes for the LM6144. In this work these pulses will be analyzed, and the three LM124 and four LM6144 waveform subsets will be presented and described in detail. This result contrasts sharply with the LM111, which presented only one characteristic pulse shape. The results on the LM124 and LM111 confirm to earlier results [1].

II. EXPERIMENT

A. Test Circuit

The LM124A operational amplifier was configured in a closed output loop with a gain of 2 as shown in Fig. 1. Sample size was a single Device Under Test (DUT). As an operational amplifier output is free to respond over the full range of supply voltages, the LM124A responded with both positive and negative output voltage pulses. DC signals of 4.30 Volts, 0.65 Volts, -0.06 Volts, -0.65 Volts, and -4.30 Volts were applied to the non-inverting inputs and \( V_{cc} \) was ±6.5 Volts for all test conditions.

The SET pulse capturing system is shown in Fig. 4. The experiment was performed at the Texas A&M Cyclotron facility. The ions and energies used in this test are given in Table 1. For all three DUTs tested, \( V_{cc} \) and \( V_{in} \) was computer controlled, which greatly reduced the chance of operator error.

The LM111 comparator was configured with a resistor pull-up on the output as shown in Fig. 2. Again sample size was a single DUT. Unlike the LM124A, the LM111 is a single sided output device and could produce only negative pulses in the configuration tested, as the output was nominally high. The input was set to either +0.02 volts, +0.05 Volts or +0.10 Volts, with \( V_{cc} \) always set at a nominal ±15 Volts.

The LM6144 was tested in three circuit configurations: an inverting amp, a non-inverting amp, and a voltage follower. These configurations are shown in Fig. 3. To facilitate this, the DUT board was designed with 6 high frequency relays. The relays allowed the DUT to be configured into all three-device applications without breaking beam. The non-inverting input was tested with 1.00 Volts, 0.65 Volts, -0.06 Volts, -0.65 Volts, and –1.00 Volts, with \( V_{cc} \) always set at a nominal ±10 Volts.

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III. EXPERIMENTAL RESULTS

A. Cross-section versus LET\textsubscript{EFF}

The cross-section curve for the LM124A at all bias conditions is shown in Fig. 5. The cross-section curve for the LM111 at both bias conditions tested is shown in Fig. 6. The cross-section curve for the LM6144 configured as an inverting amp is shown in Fig. 7, as a non-inverting amplifier in Fig. 8, and as a voltage follower in Fig. 9. For both the LM111 and LM124 these data compare favorably to previous results [1].

B. Pulse Width versus Pulse Height.

Analysis of transient pulses reveals that the SET response is complex; cross-section alone does not adequately characterize SET response. The characteristics of the SET response depend on many factors that are not necessarily controlled by the experimenter. One method to characterize this response is to measure the pulse width (the length of time that the output signal is disrupted from its non disturbed state) versus peak amplitude, or maximum pulse height of the transient signal. Here the pulse width is the distance in time that the transient signal

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**Fig. 3. Application of the LM6144**

**Fig. 4. SET Test Setup**

**Fig. 5. Cross-Section versus Effective LET of the LM124A**

**Fig. 6. Cross-Section versus Effective LET of the LM111**
begins to disrupt the quiescent signal and lasts until the transient disruption ends. This analytical approach was used by P. Adell et al. in the study of LM124 in a closed loop low power voltage regulation system [2].

Shown in Fig. 10 below is the pulse-height (V) versus pulse-width (µs) for the LM124A at a ∆V input bias of -0.06 Volts. The pulse-height versus pulse-width curve for the LM111 for all biases tested is shown in Fig. 11. The pulse-height versus pulse-width curves for the LM6144 configured as an inverting amplifier is shown in Fig. 12, non-inverting amplifier is shown in Fig. 13, and voltage follower is shown in Fig. 14.

### C. SET Pulse Shape Variations

#### 1) LM124

At -0.06 Volts input bias for the LM124A, there were three distinct families of curves within the data set.
Fig. 13. Pulse-Height versus Pulse-Width of the LM6144 configured as a non-inverting amplifier

Fig. 14. Pulse-Height versus Pulse-Width of the LM6144 configured as a voltage follower

Fig. 15. Positive Slow Pulse at 0.65 Volts Bias, Negative Pulses are Virtually the Same.

The first and second subsets consist of low amplitude pulses with relatively slow decay times, the first subset (subset A) consists of negative going transients and the second subset (subset B) of positively going transients, such as those shown in Fig. 15.

The third subset (subset C) of pulses demonstrates both fast rise and decay times, and were present as bipolar signals with small negative amplitude and large positive amplitude. These curves strongly resemble square waves in their "saturated form" as shown in Fig. 16. When the
transient amplitudes are plotted versus SET duration, the fast pulses exhibit a linear relationship until an SET amplitude of 3 Volts is reached. Beyond that point, any increase in SET duration is not reflected by an increase in amplitude. In Fig. 17 the pulse width is plotted versus pulse amplitude, with all three LM124 SET subsets or families.

2) **LM111**

The LM124A behavior contrasted sharply to that of the LM111. Only one response revealed when pulse amplitude versus pulse width was plotted (shown in Fig. 18) and further analysis showed that only one pulse shape was present.

3) **LM6144**

Examination of the LM6144 reveled the presence of four broad subsets of pulse shapes.

Subset A consisted of bipolar oscillations of short transient duration, shown in Fig. 19. As these pulses are of relatively small magnitude and short transient durations they are not expected to seriously impact system performance. The majority of transients captured were from subset A.

Subset B consists of positive going pulses with sharp onset and recovery, shown in Fig. 20. While these transients can be of large magnitude, their short duration time suggests that these pulses are of limited concern.

Subset C consists of negatively going pulses with sharp onset and recovery, shown in Fig. 21. While these transients like subset B can be of large magnitude, their short duration time also suggests that these pulses are of limited concern.

The input bias and Vcc strongly affect the magnitudes of subsets B and C. In the pulses shown the input was +0.65 Volts, therefore the output for the op-amp in the inverting amplifier with a gain of 10 will be at –6.5 Volts. With Vcc at ±10 V subset B can have amplitude of 16.5 Volts, while subset C can have at most amplitude of -3.5 Volts.

Subset D consists of long duration transient signals with moderately fast onset and recovery, shown in Fig. 22. Subset D is distinguishable from subsets B and C in several ways.

First, the polarity of subset D depends on the bias and the application tested. Negative (positive) input voltages in the inverting amplifier configuration results in positive (negative) going pulses. In a non-inverting amplifier configuration this condition is reversed where negative (positive) input voltages in the inverting amplifier configuration results in negative (positive) going pulses.

Second, the magnitude of subset D saturates at some internal voltage level, relatively far from the rails. Fig. 23 shows the saturation voltage as a function of input bias. From Fig. 23 the saturation level for inverting and non-inverting amplifiers are reflections about 0 Volt. Taking into consideration uncertainty in resistor values as well as pulse height values it appears that the saturation level for the voltage follower is related to the non-inverting amplifier saturation level through the gain. From these results testing in one configuration should yield an adequate amount of data.

These transients have smaller magnitude then subsets B or C, however their long duration time (in one event 1.5 ms) suggests that these pulses can impact a system.
IV. CONCLUSION

In this work the SET response of the LM124A, LM111, LM6144 are investigated. In this study, earlier work on the LM111 and LM 6144 was confirmed and expanded. The cross-section as well as the SET pulse duration and amplitude of all three devices were studied. Such analysis allows system designers to estimate the impact of a SET will have on circuit applications.

Table 1: Ion and Energies Used

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<th>Ion</th>
<th>Energy (MeV)</th>
<th>LET(MeV cm²/mg)</th>
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<td>Neon</td>
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Fig. 24 shows the locations of the subsets identified for the LM6144. Subsets A, B, and C fall in a narrow band, bounded by Vcc in terms of maximum amplitude, and of less then 1.7 μs transient duration.

REFERENCES