Total Dose Hardening of a Bipolar Voltage Comparator

R.L. Pease, RLP Research, Inc., Albuquerque, NM 87122
M. C. Maher, National Semiconductor, South Portland, ME, 04106
M. Savage, P. Baker, J. Krieg, and T. Turflinger, NAVSEA Crane, Crane, IN 47522
M. Shaneyfelt, Sandia Labs, Albuquerque, NM 87185

Abstract

A radiation tolerant bipolar voltage comparator experienced sever degradation in hardness when the part was re-laid out and the process moved from a 4" to a 6" line. The reasons for the loss in hardness are identified and it is shown that modifications to the design layout will re-establish the hardness.

Introduction. The LM139, quad voltage comparator, is widely used in military and space systems. The part has been extensively characterized for single event transient (SET) response [1-3] and total ionizing dose (TID) response, including enhanced low dose rate sensitivity (ELDRS) [4-6]. National Semiconductor Corporation (NSC), Military and Aerospace Division, offers the part as radiation tolerant to 100 krad(SiO_2) at high dose rate (50-300 rad(SiO_2)/s). Although the part has been shown to exhibit ELDRS, no guarantees are made for response at space like dose rates. In 2000 the high volume bipolar linear parts were moved from the 4" line in Greenock, Scotland (UK) to a 6" line in Arlington, Texas (TE). At the same time the LM139 was re-laid out to reduce the die size by 22%, primarily by eliminating unused space, without changing the symmetry of the input circuit. While the high dose rate hardness of the UK part consistently met 100 krad(SiO_2), the TE part was found to pass at 10 krad(SiO_2) but fail at 30 krad(SiO_2). Recent studies on the NSC LM111 voltage comparator have shown that the TID and ELDRS responses are very sensitive to pre-irradiation thermal stress (PETS) and that the passivation layer affects both the ELDRS and PETS response [7]. Thus it was not known whether the reduction in hardness of the TE LM139 was a result of changes in the process or changes in the layout. In this summary we describes the nature of the reduced hardness of the TE LM139 compared to the UK LM139, identify and verify the failure mechanisms, and demonstrate solutions that improve the total dose response of the TE LM139.

Comparison of UK and TE total dose response. The LM139 is lot sample tested for total dose response by NSC using a biased irradiation at 50-300 rad(SiO_2)/s in a Co-60 irradiator at the Military and Aerospace Division in South Portland, ME. The standard sample size is 6 packages and the step-stress total dose levels are 3, 10, 30, 50, 80 and 100 krad(SiO_2). The LM139 consists of 4 independent voltage comparators. While all specification parameters are measured for each comparator before and after each irradiation step, the parameters of primary interest were offset voltage, Vos, input bias current, Ib+ and Ib-, input offset current, Ios, and propagation time. The average (+/- 1 stdev) radiation-induced change in Vos (ΔVos) and Ib+ (ΔIb+) are shown in Figures 1 and 2, respectively, for a typical UK 4" wafer lot (fabricated in January 2001) and in Figures 3 and 4, respectively, for a TE 6" wafer lot (fabricated in September 2000). For the UK devices we observe no significant differences in the radiation response of ΔVos or ΔIb+ between the four comparators. Also the standard deviations are very small. On the other hand, for the TE parts we observe a dramatic difference in the ΔVos radiation response of comparator 1 versus the other three comparators as shown in Figure 3. In the TE lot comparator 1 is completely out of specification at 30 krad(SiO_2) and is negative going while the other three comparators are below 5 mV at 100 krad(SiO_2) and two are positive going.

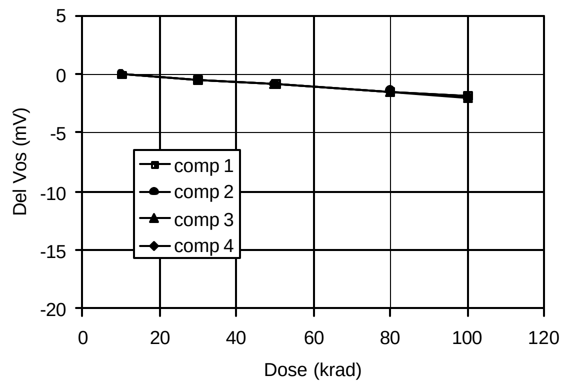

Figure 1. UK 4" LM139 ave. change in Vos vs. dose

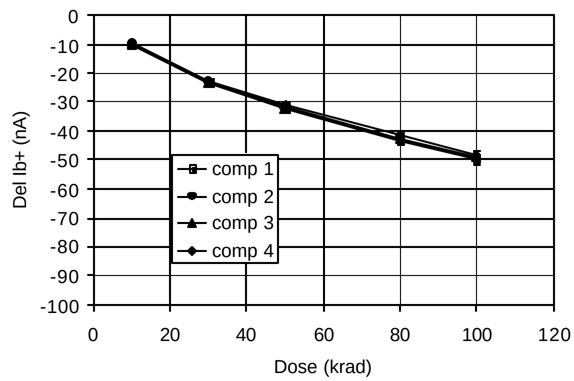

Figure 2. UK 4" LM139 ave. change in Ib+ vs. dose

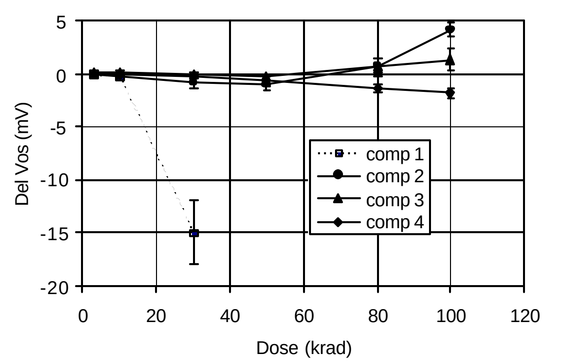

Figure 3. TE 6" LM139 ave. change in Vos vs. dose

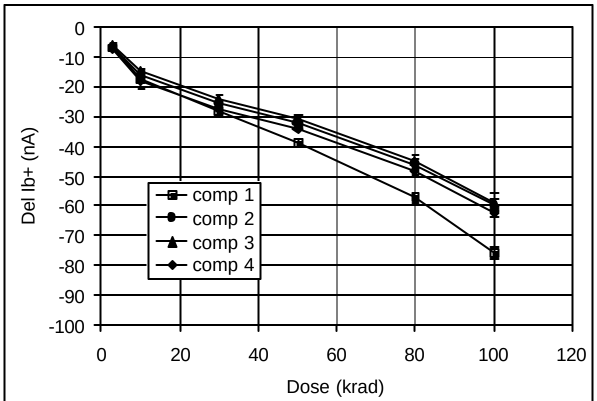

Figure 4. TE 6" LM139 ave. change in Ib+ vs. dose

In the UK devices there was a nearly linear degradation of ΔVos toward negative values up to 100 krad(SiO_2). Comparing Figures 2 and 4 it is clear that while the degradation of ΔIb+ is somewhat greater in the TE devices than the UK devices the differences are not great. In addition, TE comparator 1 shows about a 30% higher degradation at 100 krad(SiO_2) than the other three comparators.

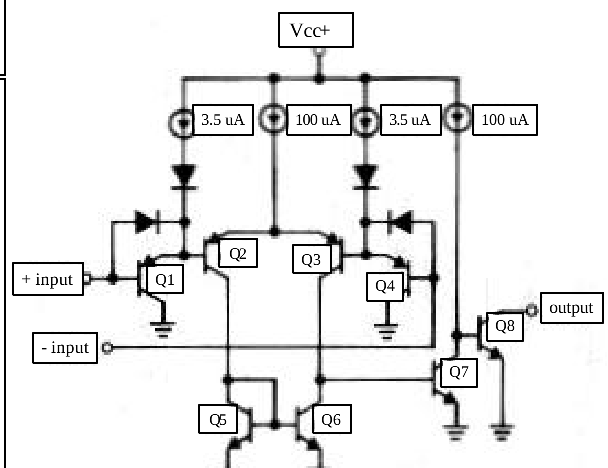

Figure 5. Simplified circuit diagram of LM139.

A simplified circuit diagram of the LM139 is shown in Figure 5. Inspection of the old and new LM139 layouts reveals no significant differences in the layout of the input circuit, which includes Q1-4 and the four diodes. Since the degradation of Ib+ is primarily a result of the total dose induced increase in base current in Q1, and the layout of Q1 did not change, it is reasonable to conclude that the differences between the degradation seen in Figure 2 and 4 are, in fact due to differences in the fabrication process or lot-to-lot variations. While this difference is measurable it would not account for degradation in hardness from 100 krad(SiO_2) to below 30 krad(SiO_2) or explain the asymmetry in Vos degradation of TE comparator 1 compared to the other three TE comparators. It appears that the dramatic difference in the Vos degradation of comparator 1 in the TE devices is a result of a layout asymmetry. This observation was verified with total dose testing on wafer lots fabricated in two other NSC facilities using the same 22% die shrink layout as used for the TE 6" wafer lots (the reduced total dose response has been observed on multiple lots in the Arlington Texas facility). Since there was no apparent difference in the old or new layout of the input circuit between the four comparators on the die and process modifications have been ruled out, our next step was to look for layout asymmetry in another part of the circuit that could account for the rapid Vos degradation in comparator 1.

Identification and verification of Vos mechanism. It is well known that if metal at a high positive voltage passes over the active base region of an npn transistor it can cause enhanced positive charge trapping in the base oxide and enhanced degradation of base current, hence current gain. Higher gain degradation in one transistor of a balance pair will lead to an offset. Based on this reasoning the new layout was carefully reviewed to identify any transistors where the Vcc line crossed over or near an active base region to a greater extent in comparator 1 than in the other comparators. Such a region was found on transistor Q5 in the current mirror formed by Q5 and Q6 shown in Figure 5. The region (marked by the red shaded rectangles) is shown in Figure 6a, which is a photomicrograph of Q5 in the new layout of comparator 1. For comparison the old layout of comparator 1 is shown in Figure 6b.

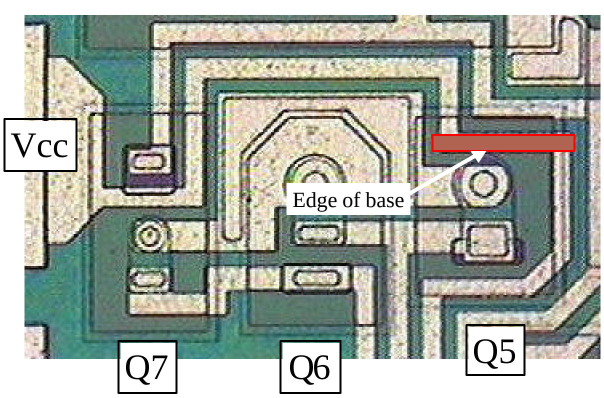

Figure 6a. New LM139 layout of comparator 1 showing Vcc metal over Q5

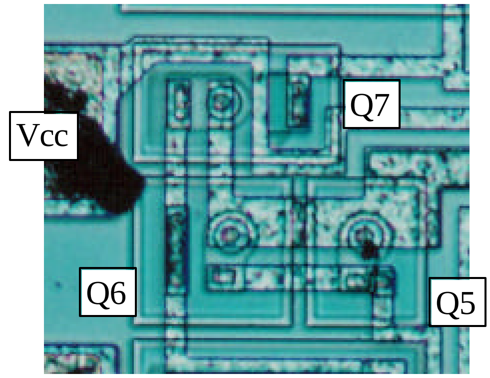

Figure 6b. Old LM139 layout of comparator 1 with no Vcc metal over Q5

Although Vcc metal passes over the active area of Q7, it does so in a similar fashion in the old and new layouts, and it passes over Q7 in the same manner on comparators 2 and 3 in both layouts. Thus it was eliminated as the primary source of the problem. Since it appeared that the metal over Q5 might cause enhanced degradation in comparator 1 compared to the other three comparators, an experiment was performed to measure the degraded I-V characteristic of Q5 for all four comparators. An LM139 that had been irradiated to 50 krad(SiO_2) was used for the experiment. Q5 was isolated on all four comparators and the I-V characteristic measured. The results are shown in Figure 7.

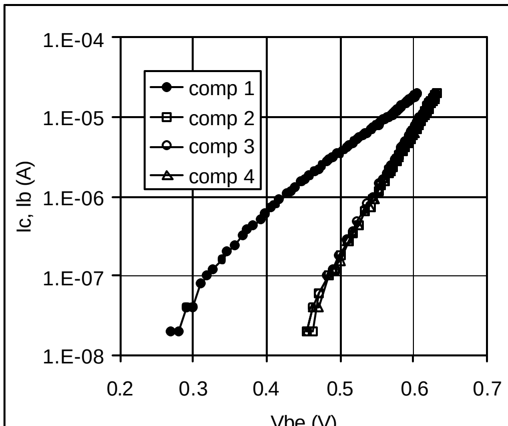

Figure 7. Q5 IV curves for part irradiated to 50 krad

It is clear that Q5 is degraded much more in comparator 1 than in the other three comparators, which have essentially the same I-V curve. Examination of Figure 5 shows that Q5 and Q6 in the current mirror have their bases tied together and emitters tied to ground and hence operate at the same Vbe. If Q5 draws more current than Q6 in comparator 1 then it will cause an imbalance in the emitter current of Q1 relative to Q4. This imbalance in emitter currents will cause an increased offset voltage, Vos. Data on Q6 was taken to verify the difference between Q5 and Q6 in comparator 1 and the other comparators. A SPICE circuit analysis was performed to verify the increased Vos due to the enhanced degradation of Q5. The results will be shown in the final paper. Further verification of this mechanism has been obtained by stitch bonding from the lead frame directly to the Vcc line on the other side of Q5, and cutting loose the metal over Q5. The Vcc bond pad was then grounded, which grounds the metal over Q5. Biased irradiation results for these devices show comparator 1 Vos within specification through 100 krad(SiO_2). Based on this work NSC performed a re-layout of the LM139 to move the Vcc metal away from the base area of Q5. Results of this layout fix will be presented in the final paper.

Summary. The National LM139 was sold as a radiation tolerant part to 100 krad(SiO_2) at high dose rate (50-300 rad(SiO_2)/s) when it was fabricated on the 4" line in Greenock, Scotland (UK). When the fabrication was moved to a 6" line in Arlington, Texas and the part was re-laid out for a 22% die shrink, the hardness fell below 30 krad due an enhanced degradation of Vos in comparator 1. Investigation of the layout was used to identify a suspect region where Vcc metal passed over the active area on one of the transistors in the current mirror in comparator 1, but not on the other comparators. Microprobe measurements, SPICE simulations, and radiation results have confirmed this as the cause of the reduced hardness. NSC performed a re-layout of the LM139 Vcc metal to avoid the base region on Q5. These results demonstrate how sensitive the total dose response of a bipolar linear circuit can be to modifications in the metalization layout.

Acknowledgements. This work was sponsored by the United States Department of Energy and by the DTRA Radiation Tolerant Microelectronics program with NAVSEA Crane under contract N00164-97-D-0013 and Sandia National Laboratories. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000. The authors would like to thank Lew Cohn for his enthusiastic support. The authors would also like to thank Alan Johnston of JPL, Dr. Ron Schrimpf of Vanderbilt and Fred Barsun of NAVSEA Crane for technical discussions.

References.

[1] D. K. Nichols, J. R. Coss, T. F. Miyahira and H. R. Schwartz, "Heavy Ion and Proton Induced Single Event Transients in Comparators, IEEE Trans. Nucl. Sci., 43, 2960-2967, 1996.

[2] R. Koga, S. H. Penzin, K. B. Crawford, W. R. Crain, S. C. Moss, S. D. Pinkerton, S. D. LaLumondiere and M. C. Maher, "Single Event Upset (SEU) Sensitivity Dependence of Linear Integrated Circuits (ICs) on Bias Conditions", IEEE Trans. Nucl. Sci., 44, 2325-2332, 1997

[3] R. Harboe-Sorensen, F. X. Guerre, H. Constans, J. van Dooren, G. Berger and W Hajdas, "Single Event Transient SEU Characterization of Analog ICs for ESA's Satellite, Proceedings of RADECS 99, 573-581, 1999.

[4] S. McClure, R. L. Pease, W. Will and G. Perry, "Dependence of Total Dose Response of Bipolar Linear Microcircuits on Applied Dose Rate", IEEE Trans. Nucl. Sci., Vol. 41, pp. 2544, 1994.

[5] Pease, R. L., W. E. Combs, A. Johnston, T. Carriere, C. Poivey, A. Gach, and S. McClure, "A Compendium of Recent Total Dose Data on Bipolar Linear Microcircuits", IEEE Rad. Effects Data Workshop Record, 28-37, 1996.

[6] Pease, R. L., S. McClure, A. H. Johnston, J. Gorelick, T. L. Turflinger, M. Gehlhausen, J. Krieg, T. Carriere, and M. Shaneyfelt, "An Updated Compendium of Enhanced Low Dose Rate Sensitive (ELDRS) Bipolar Linear Circuits", IEEE Rad. Effects Data Workshop Record, 127-133, 2001.

[7] Shaneyfelt, M. R., J. R. Witczak, J. R. Schwank, D. M. Fleetwood, R. L. Pease, P. S. Winokur, L. C. Riewe and G. L. Hash, "Thermal-Stress Effects on Enhanced Low Dose Rate Sensitivity in Linear Bipolar ICs", IEEE Trans. Nucl. Sci. NS-47, No.6, 2539-2545, 2000.