Low dose rate testing of the Intersil HS9S-117RH positive linear voltage regulator

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Nick van Vonno
Intersil Corporation

Abstract:

This document provides a brief introduction to low dose rate effects including discussion of Intersil's approach to testing and qualification issues. We then report results of baseline 100krad(Si) low dose rate testing of the Intersil HS9S-117RH positive linear voltage regulator.

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1: Introduction: What is Low Dose Rate Sensitivity?

Low dose rate effects have been a topic of considerable research interest for the last eight years. The first section of this report will supply a brief technical introduction to the topic.

Total ionizing dose testing of semiconductor components has historically been performed at 'qualification' dose rates in the 50 – 300rad(Si)/s range as specified in MIL-STD-883. At 50rad(Si)/s, the low end of the dose rate specification range, a lot qualification test to a 300krad(Si) total dose specification takes a maximum of 1.67 hours, enabling the test to be carried out in less than a day. Intersil has historically performed total dose qualification testing of their hardened parts on a wafer by wafer basis, using Gammacell 220 ™ irradiators; the dose rate of the current Intersil Gammacell is approximately 130rad(Si)/s, and the 300krad(Si) test takes 38 minutes.

In the 1992 – 1993 time frame, researchers at Mission Research and Aerospace Corporation noted surprising dose rate dependence in the total dose response of bipolar analog integrated circuits. Devices such as the industry-standard LM139 comparator showed severe degradation of such parameters as input bias current and input offset voltage when irradiated at very low dose rates. This enhanced low dose rate sensitivity (ELDRS) was subsequently observed in a broad range of bipolar and BiCMOS parts, but has not been seen in MOS parts (except in a very few unconfirmed cases in discrete MOS devices). In MOS parts the effects of low dose rate are opposite to those observed in bipolars; the damage anneals out at a constant rate, so lower dose rate testing causes less degradation, which is a much more intuitive result. Figure 1 shows a well-known if somewhat extreme sample response curve [1] for a bipolar operational amplifier.

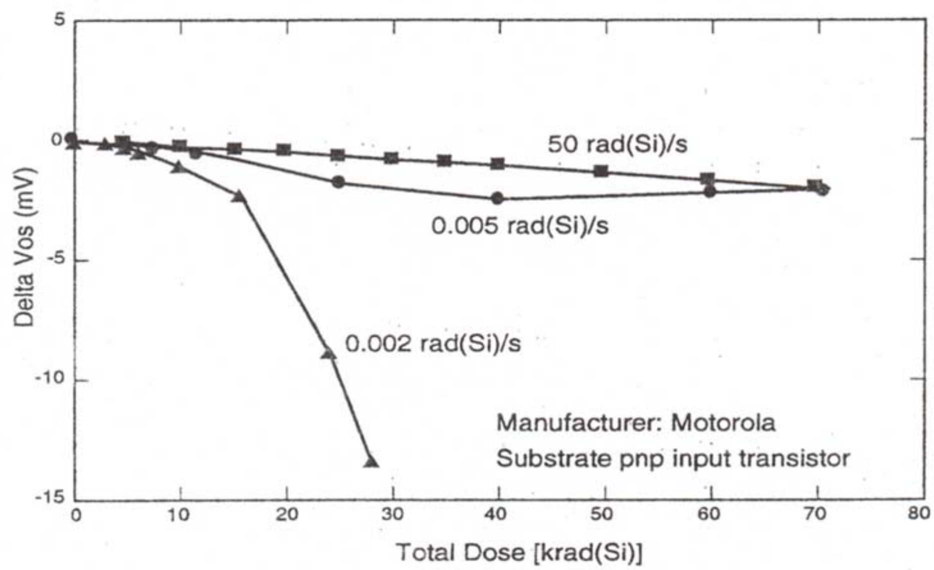

Figure 1: ***Where is the bottom?*** Degradation of the input bias current of the Motorola LM328 operational amplifier at three dose rates [1]. Note that the input offset voltage as a function of total dose shows excellent stability at the 50rad(Si)/s and .005rad(Si)/s dose rates, but degrades rapidly at the very low .002rad(Si)/s dose rate.

Following the initial findings in 1992, low dose rate sensitivity developed into one of the premier research topics in the radiation effects community, as evidenced by a large number of journal papers. Compendia of low dose rate results for a broad range of commercially available parts are particularly useful; these compendia [2] and other papers on the subject can be found in the IEEE Radiation Effects Data Workshop Record, which is published yearly and contains papers presented at the Workshop. The December issue of the IEEE Transactions on Nuclear Science serves as the proceedings of the IEEE Nuclear and Space Radiation Effects Conference (NSREC) and is another excellent source of technical information on low dose rate effects.

There has been significant work on identifying a basic mechanism that explains this effect, with mixed success. The theories relate to trapping and detrapping rates in the IC's dielectric thin film layers. A detailed discussion of the basic mechanisms of ELDRS is outside the scope of this document. Note that the initial work suggested that the worst-case condition in all cases was zero bias during irradiation; this conclusion has subsequently been disproved. Intersil testing of the HS1825ASRH pulse width modulator has shown bias sensitivity, in disagreement with the early claims made in the literature, and showed distinctive failure signatures for each of the bias configurations used. The requirement for biased irradiation requires fixture design and construction and further complicates testing procedures. Clearly, many different bias configurations are possible; Intersil's approach to managing this problem has been to use the same bias configurations for both low and high dose rate testing. To this end, we use the irradiation bias circuit specified in the applicable SMD. This approach enables comparison of results for both dose rate ranges.

ELDRS has proven to be a somewhat unpredictable and poorly repeatable effect. There are well-documented large variations within processes and across similar processes built in different fabrication facilities. Packaging, especially in plastic, seems to play a role as well, as do heat treats incurred during burnin.

Due to the very low dose rates used, low dose rate tests take an inordinately long time, at least when viewed in the context of normal qualification tests. The numbers are inescapable: a simple 100krad(Si) qualification test at a dose rate of .01rad(Si)/s takes 116 days, or nearly four months, not including pre- and post-irradiation characterization testing. Clearly, this is not a practical procedure in any for-profit organization, and a substantial amount of research has gone into the development of accelerated test methods. Harris Corporation and Intersil researchers have developed [3] an accelerated ELDRS test that has shown reasonable correlation to true low dose rate testing at the part level, while internal Intersil tests (these at the transistor level) have shown good correlation. The method tests the parts at a moderate dose rate of about 10rad(Si)/s and at a temperature of 100^{o}C, which reduces the 100krad(Si) irradiation time to about three hours. User acceptance of such options will be a key factor in determining participation in this market by IC vendors. For the present, though, accelerated testing is used as a diagnostic for low dose rate sensitivity only.

Again due to the low dose rates needed, current Gammacell 220™ sources are not readily usable. The dose rates of these ^{60}Co sources cannot conveniently be reduced to the 5rad(Si)/s required by the current MIL-STD-883 Method 1019.7 accelerated test option, let alone to the .01rad(Si)/s true low dose rate requirement. The Gammacell interior is very cramped, and can accommodate only a few samples in a small fixture. Low dose rate sources are available from J. L. Shepherd and Associates (San Fernando, CA), and Intersil uses a Model 484 irradiator from this vendor.

Intersil uses dielectrically isolated (DI) fabrication processes for its hardened analog parts. This positively eliminates latchup, either electrically or single-event caused, and also enables the use of a vertical PNP bipolar transistor of greatly enhanced electrical performance as compared to lateral devices. Intersil expected these vertical PNP structures to show reduced sensitivity to low dose rate based on the known softness of the lateral PNP transistors encountered in commercial junction isolated (JI) processes. Radiation tests performed in the context of routine device modeling work had shown our vertical devices to be much harder than laterals at qualification dose rates in the 50 – 300rad(Si)/s range, and it was expected that the low dose rate response of the vertical PNP device would track its response at high dose rate.

Workers outside and inside Intersil have verified this assumption. In 1999 researchers at NAVSEA/Crane published a paper [5] reporting positive results for the HS9-139RH quad comparator, which was found to be within its post-radiation parametric limits after 300krad(Si) at .01rad(Si)/s. An in-house baseline 100krad(Si) low dose rate test of the HS9-139RH quad comparator at Intersil is complete, with all parts within the SMD post-radiation specifications after irradiation. Additionally, U.S. Navy testing of the Intersil ISL72991RH low dropout adjustable negative regulator has shown similarly good results; this data is yet unpublished.

2: Low Dose Rate Testing Strategy at Intersil

The long test times encountered make conventional wafer-by-wafer qualification testing at low dose rate an impractical proposition, and Intersil does not plan to support this approach. In Intersil's approach, the standard MIL-STD-883 Method 1019.7 high dose rate qualification testing will be supplemented by baseline low dose rate characterization testing on a part-by-part basis. Reports summarizing these tests will be posted on the Intersil Web site.

To this end Intersil has procured a J. L. Shepherd and Associates model 484 low dose rate ^{60}Co irradiator. This equipment is capable of dose rates of .01rad(Si)/s and is now on line in Intersil's Palm Bay, Florida facility. Appropriate fixturing to perform these tests in accordance with the requirements of MIL-STD-883 Method 1019.7 has been constructed and installed. All testing is performed under bias. The fixturing uses the same test boards as the Intersil high dose rate Gammacell 220 ™ facility; the test configuration and bias voltages are the same as well, insuring a valid comparison between the results of low and high dose rate testing. During irradiation the devices under test are enclosed in a PbAl box, as specified by MIL-STD-883 Method 1019.7. in order to filter out low-energy photons caused by backscattering effects. We use Far West Technology, Inc. (Goleta, CA) model FWT-70 Opti-Chromic radiochromic dosimeters to monitor accumulated dose. Test samples are taken from burned-in production part inventory, as burnin and its attendant heat treats have been shown [4] to play a role in low dose rate response.

3: Low Dose Rate Testing of the Intersil HS9S-117RH Positive Voltage Regulator

The balance of this report covers results of a low dose rate test of the Intersil HS9S-117RH positive linear voltage regulator. Parts were tested at .01rad(Si)/second and were packaged in the 3-lead TO-220 power package.

The radiation hardened HS9S-117RH is an adjustable positive linear voltage regulator capable of operating with input voltages up to 40VDC. The output voltage is adjustable from 1.2V to 37V with two external resistors. The device is capable of sourcing from 5mA to $1.25A_{PEAK}$ ($0.5\ A_{PEAK}$ for the TO-39 package). On-chip thermal shutdown and output current limiting circuitry provide overload protection. The HS9S-117RH is constructed using the Intersil dielectrically isolated radiation hardened Silicon Gate (RSG) process. The part is immune to single event latch-up and has been specifically designed to provide highly reliable performance in harsh radiation environments.

Standard Microcircuit Drawings (SMD) for radiation-hardened QML devices are controlled by the Defense Supply Center in Columbus, OH (DSCC). Detailed electrical specifications for the HS9S-117RH are contained in SMD 5962-99547. The Intersil Web site provides a "hot-link" for downloading the data sheet and SMD for this part.

Intersil has completed a baseline in-house test of the HS9S-117RH at a true low dose rate of 10 millirad(Si)/s. Samples were irradiated to a total dose of 100krad(Si). The test used the J. L. Shepherd and Associates model 484 low dose rate irradiator installed at the Intersil Palm Bay, Florida facility. The sample size for this test was 12, and the parts were irradiated per MIL-STD-883 Method 1019 using the irradiation bias configuration specified in the applicable SMD (see Figure 2, below). This irradiation bias is used to permit a more direct comparison between low and high dose rate results. Note also that the 'all pins grounded' configuration is not always worst case, and Intersil researchers have reported biased irradiation to be in fact worst-case for some RSG parts. Downpoint testing was performed using the standard automated test equipment (ATE) procedure used for production testing as well. The results of this test are summarized in Figures 3 – 6, below. Monitored parameters included reference voltage, line and load regulation and adjust pin current.

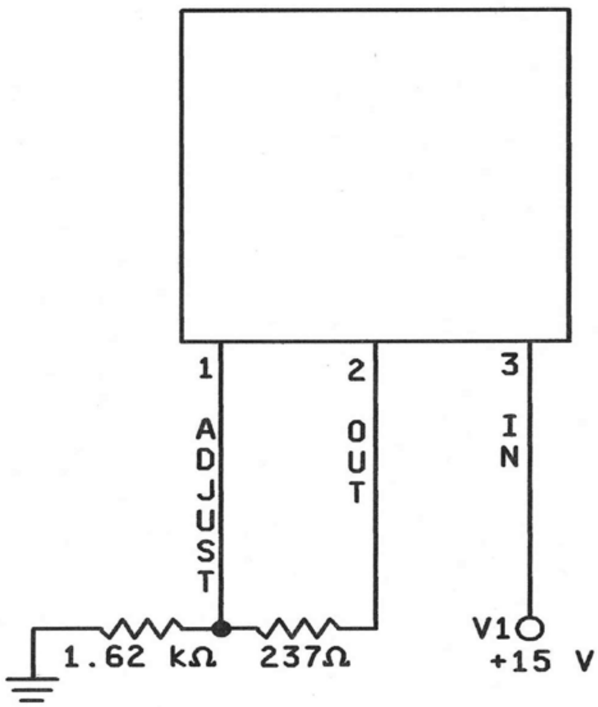

Figure 2: HS9S-117RH irradiation bias configuration per SMD 5962-99547.

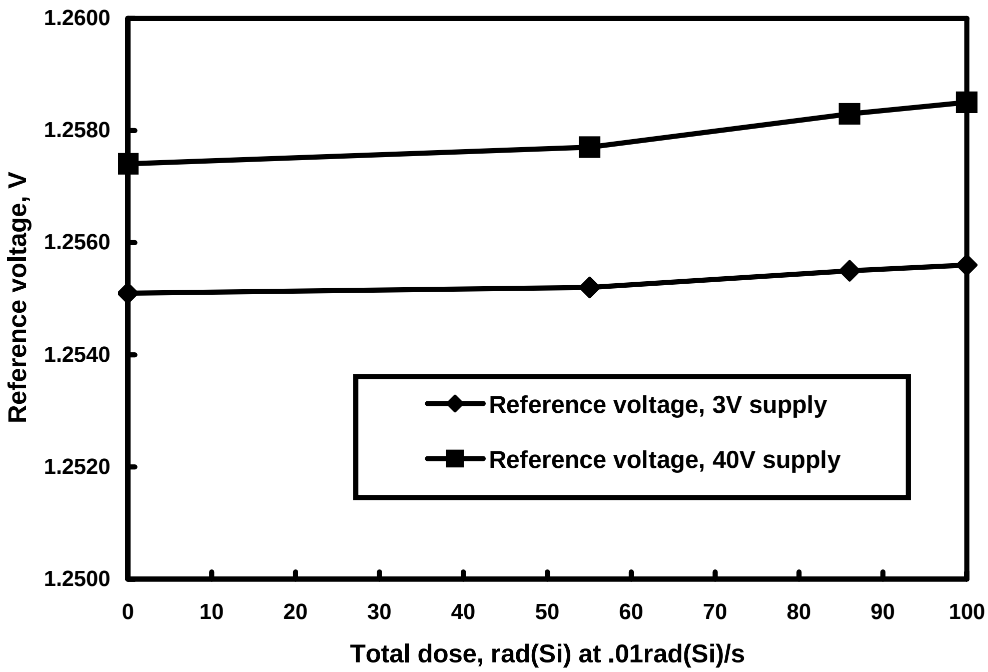

Figure 3: HS9S-117RH average reference voltage as a function of total dose. Sample size was 12 parts. The maximum post-radiation reference voltage specification range is 1.2 – 1.3V.

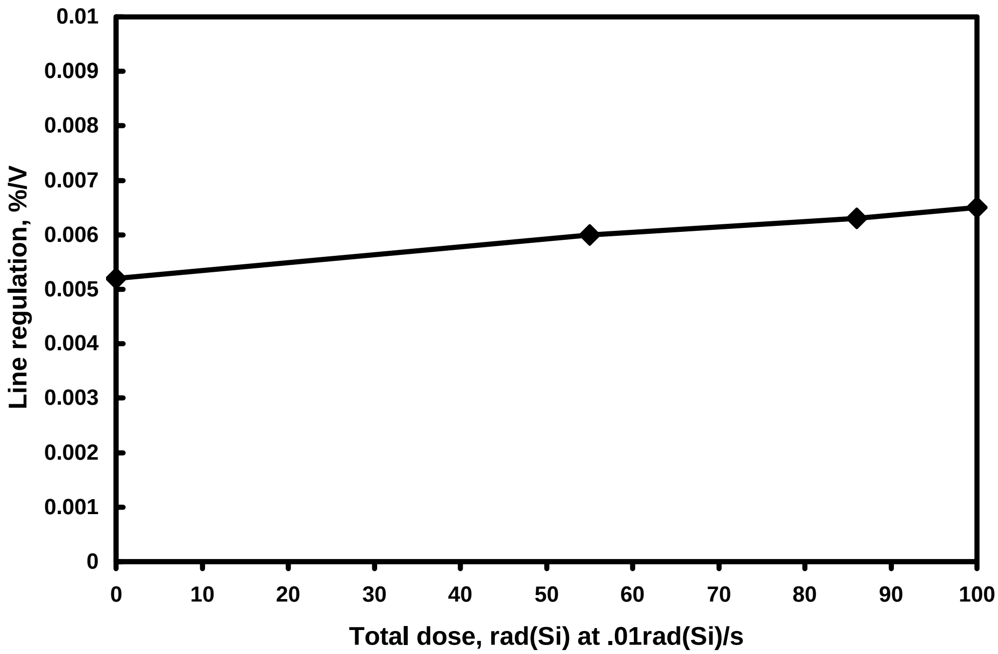

Figure 4: HS9S-117RH average line regulation as a function of total dose. Sample size was 12 parts. The maximum post-radiation line regulation specification is +/- .02%/V.

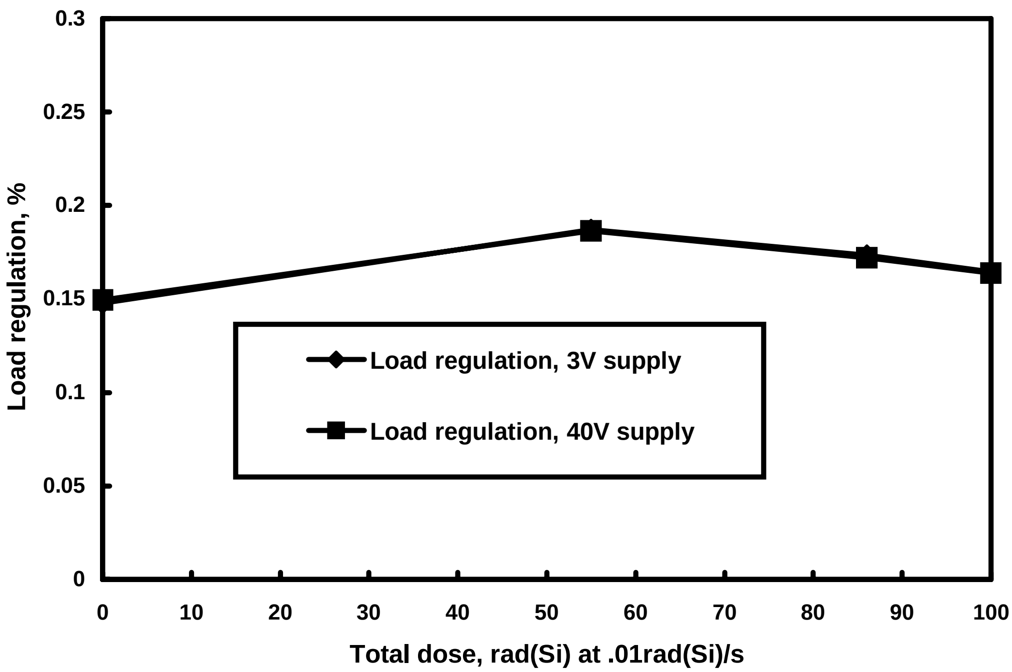

Figure 5: HS9S-117RH average load regulation as a function of total dose. Sample size was 12 parts. The maximum post-radiation load regulation specification is +/- 1.5 %.

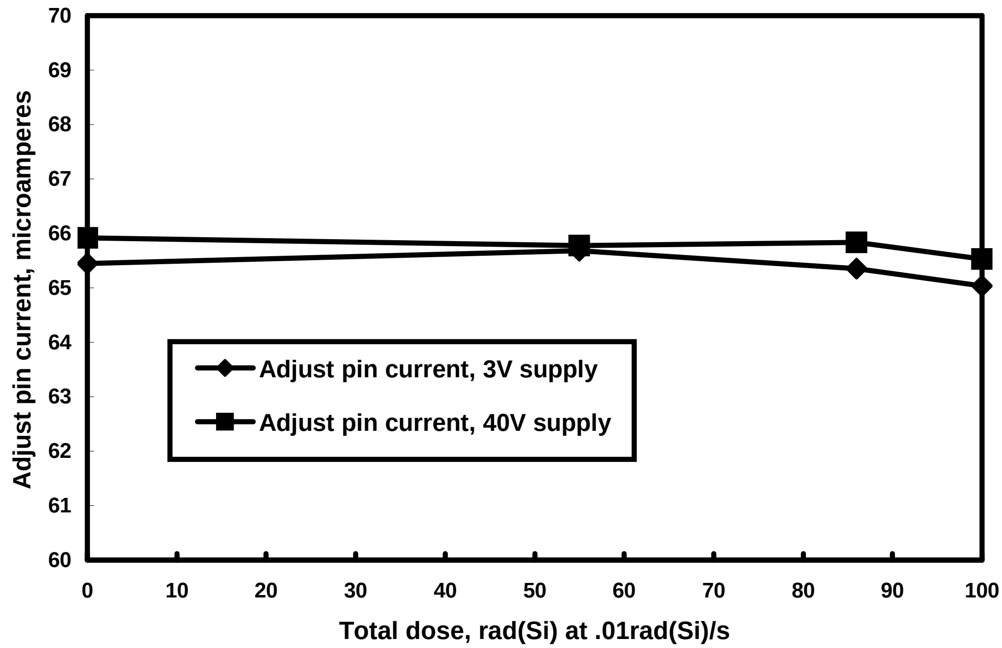

Figure 6: HS9S-117RH average adjust pin current as a function of total dose. Sample size was 12 parts. The maximum post-radiation adjust pin current specification is 100 microamperes.

The HS9S-117RH is built in the Intersil RSG process, which has been shown to have moderate ELDRS sensitivity. The data shows excellent stability of the reference voltage generated by an on-chip bandgap reference. Line regulation, load regulation and adjust pin current show similar good stability. Based on the accelerated test, we conclude that the HS9S-117RH shows little or no low dose rate sensitivity after irradiation to 100krad(Si).

5: Conclusion

This document provides technical background, data and conclusions on a low dose rate test of the HS9S-117RH positive linear voltage regulator. The part showed little or no low dose rate sensitivity after 100krad(Si).

6: References

[1] A.H. Johnston, C.I. Lee and B. G. Rax, 'Enhanced Damage in Bipolar Devices at Low Dose Rates: Effects at Very Low Dose Rates', *IEEE Transactions on Nuclear Science, December 2002.*

[2] R. L. Pease, S. S. McClure, A. H. Johnston, J. Gorelick, T. L. Turflinger, M. Gehlhausen, J. Krieg, T. Carriere and M. R. Shaneyfelt, 'An Update Data Compendium of Enhanced Low Dose Sensitive (ELDRS) Bipolar Linear Circuits', *IEEE 2001 Radiation Effects Data Workshop Record, July 2001.*

[3] W. Abare, F. Brueggeman, R. L. Pease, J. Krieg and M. Simons, 'Comparative Analysis of Low Dose Rate, Accelerated and Standard Cobalt-60 Radiation Response Data for a Low-Dropout Voltage Regulator and a Voltage Reference', *IEEE 2002 Radiation Effects Data Workshop Record, July 2001.*

[4] J. F. Krieg, J. L. Titus, D. Emily, M. Gehlhausen, J. W. Swonger and D. C. Platteter, 'Enhanced Low Dose Rate Sensitivity (ELDRS) in a Voltage Comparator which only Utilizes Complementary Vertical NPN and PNP Transistors', *IEEE Transactions on Nuclear Science, December 1999.*

[5] M. R. Shaneyfelt et al., 'Elimination of Enhanced Low-Dose-Rate Sensitivity and Thermal Stress Effects in Linear Bipolar Devices', *IEEE Transactions on Nuclear Science, December 2002.*

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Nick van Vonno
Intersil Corporation