Radiation Assured Devices
5017 N. 30th Street
Colorado Springs, CO 80919
(719) 531-0800

Radiation Lot Acceptance Testing (RLAT) of the RH1009MH 2.5V Voltage Reference for Linear Technology

Customer: Linear Technology, PO# 53080L

RAD Job Number: 09-270

Part Type Tested: Linear Technology RH1009MH 2.5V Reference

Traceability Information: Fab lot# WP1399, Wafer# 3, Assembly Lot #517221.1. Information obtained from Linear Technology PO#53080L. Date code marking on the package is 0919A. See Appendix A for a photograph of the device and part markings.

Quantity of Units: 12 units total, 5 units for biased irradiation, 5 units for unbiased irradiation and 2 control units. Serial numbers 1164 to 1168 were biased during irradiation. Serial numbers 1169 to 1173 were unbiased during irradiation (all pins tied to ground). Serial numbers 1174 and 1175 were used as controls. See Appendix B for the radiation bias connection table.

External Traveler: None required

Pre-Irradiation Burn-In: Burn-In performed by Linear Devices prior to receipt by RAD.

TID Dose Rate and Test Increments: 50-300rad(Si)/s with readings at pre-irradiation, 20, 50, 100, and 200krad(Si).

TID Overtest and Post-Irradiation Anneal: No overtest or anneal.

TID Test Standard: MIL-STD-883G, Method 1019.7, Condition A

TID Electrical Test Conditions: Pre-irradiation, and within one hour following each radiation exposure.

Test Hardware: LTS2020 Tester, Entity ID: TS03, Calibration Date 4/28/09, Calibration Due 04/28/10.

Facility and Radiation Source: Radiation Assured Devices Longmire Laboratories, Colorado Springs, CO using the JLSA 81-24 high dose rate Co60 source. Dosimetry performed by CaF TLDs traceable to NIST. RAD's dosimetry has been audited by DSCC and RAD has been awarded Laboratory Suitability for MIL-STD-750 TM 1019.5.

Irradiation and Test Temperature: Ambient room temperature for irradiation and test of 24°C ± 6°C per MIL STD 883.

RLAT Result: PASSED. Units Passed to 200krad(Si) with no significant degradation to any of the measured parameters.

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1.0. Overview and Background

It is well known that total dose ionizing radiation can cause parametric degradation and ultimately functional failure in electronic devices. The damage occurs via electron-hole pair production, transport and trapping in the dielectric and interface regions. In discrete devices the bulk of the damage is frequently manifested as a reduction in the gain and/or breakdown voltage of the device. The damage will usually anneal with time following the end of the radiation exposure. Due to this annealing, and to ensure a worst-case test condition MIL-STD-883 TM1019.7 calls out a dose rate of 50 to 300rad(Si)/s as Condition A and further specifies that the time from the end of an incremental radiation exposure and electrical testing shall be 1-hour or less and the total time from the end of one incremental irradiation to the beginning of the next incremental radiation step should be 2-hours or less. The work described in this report was performed to meet MIL-STD-883 TM1019.7 Condition A.

2.0. Radiation Test Apparatus

The total ionizing dose testing described in this final report was performed using the facilities at Radiation Assured Devices' Longmire Laboratories in Colorado Springs, CO. The high dose rate total ionizing dose (TID) source is a JLSA 84-21 irradiator modified to provide a panoramic exposure. The Co-60 rods are held in the base of the irradiator heavily shielded by lead, during the radiation exposures the rod is raised by an electronic timer/controller and the exposure is performed in air. The dose rate for this irradiator in this configuration ranges from <1rad(Si)/s to a maximum of approximately 120rad(Si)/s, determined by the distance from the source. For high-dose rate experiments the bias boards are placed in a radial fashion equidistant from the raised Co-60 rods with the distance adjusted to provide the required dose rate. The irradiator calibration is maintained by Radiation Assured Devices Longmire Laboratories using thermoluminescent dosimeters (TLDs)) traceable to the National Institute of Standards and Technology (NIST). Figure 2.1 shows a photograph of the JLSA 81-24 Co-60 irradiator at RAD's Longmire Laboratory facility.

RAD is currently certified by the Defense Supply Center Columbus (DSCC) for Laboratory Suitability under MIL STD 750. Additional details regarding Radiation Assured Devices dosimetry for TM1019 Condition A testing are available in RAD's report to DSCC entitled: "Dose Rate Mapping of the J.L. Shepherd and Associates Model 81 Irradiator Installed by Radiation Assured Devices"

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Figure 2.1. Radiation Assured Devices' high dose rate Co-60 irradiator. The dose rate is obtained by positioning the device-under-test at a fixed distance from the gamma cell. The dose rate for this irradiator varies from approximately 120rad(Si)/s close to the rods down to 1rad(Si)/s at a distance of approximately 2-feet.

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3.0. Radiation Test Conditions

The RH1009 dual 2.5V Voltage References described in this final report were irradiated using a single 15V supply and with all pins tied to ground, that is biased and unbiased. See the TID Bias Table in Appendix B for the full bias circuits. These bias circuits satisfy the requirements of MIL-STD-883G TM1019.7 Section 3.9.3 Bias and Loading Conditions which states "The bias applied to the test devices shall be selected to produce the greatest radiation induced damage or the worst-case damage for the intended application, if known. While maximum voltage is often worst case some bipolar linear device parameters (e.g. input bias current or maximum output load current) exhibit more degradation with 0 V bias."

The devices were irradiated to a maximum total ionizing dose level of 200krad(Si) with incremental readings at 20, 50, 100 and 200krad(Si). Electrical testing occurred within one hour following the end of each irradiation segment. For intermediate irradiations, the parts were tested and returned to total dose exposure within two hours from the end of the previous radiation increment.

The TID bias board was positioned in the Co-60 cell to provide the required minimum of 50rad(Si)/s and was located inside a lead-aluminum enclosure. The lead-aluminum enclosure is required under MIL-STD-883G TM1019.7 Section 3.4 that reads as follows: "Lead/Aluminum (Pb/Al) container. Test specimens shall be enclosed in a Pb/Al container to minimize dose enhancement effects caused by low-energy, scattered radiation. A minimum of 1.5 mm Pb, surrounding an inner shield of at least 0.7 mm Al, is required. This Pb/Al container produces an approximate charged particle equilibrium for Si and for TLDs such as CaF2. The radiation field intensity shall be measured inside the Pb/Al container (1) initially, (2) when the source is changed, or (3) when the orientation or configuration of the source, container, or test-fixture is changed. This measurement shall be performed by placing a dosimeter (e.g., a TLD) in the device-irradiation container at the approximate test-device position. If it can be demonstrated that low energy scattered radiation is small enough that it will not cause dosimetry errors due to dose enhancement, the Pb/Al container may be omitted".

The final dose rate within the high dose rate lead-aluminum enclosure was determined based on TLD dosimetry measurements (see previous section). The final dose rate for this work was 86.8rad(Si)/s with a precision of ±5%.

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4.0. Tested Parameters

During the radiation lot acceptance testing the following pre- and post-irradiation electrical parameters were measured:

1. Reverse Breakdown Voltage, V_Z (V)
2. Reverse Breakdown Voltage Change with Current, $\Delta V_Z / \Delta I_Z$ (V)
3. Reverse Dynamic Impedance. R_Z (Ω)

The parametric data was obtained as read and record and all the raw data plus an attributes summary are contained in a separate Excel file. The attributes data contains the average, standard deviation and the average with the KTL values applied. The KTL value used is 2.742 per MIL HDBK 814 using one sided tolerance limits of 90/90 and a 5-piece sample size. Note that the following criteria must be met for a device to pass the RLAT: following the radiation exposure each of the 5 pieces shall pass the specification value and the average value for the ten-piece sample must pass the specification value when the KTL limits are applied. If either of these conditions is not satisfied following the radiation exposure, then the lot could be logged as a failure.

5.0. Total Ionizing Dose Test Results

The RH1009 2.5V Voltage References PASSED the RLAT to the maximum tested total dose of 200krad(Si) with no significant degradation to any of the measured parameters. Figures 5.1 and 5.3 show plots of all the measured parameters versus total ionizing dose while Tables 5.1 – 5.3 show the corresponding raw data for each of these parameters.

In the data plots the solid diamonds are the average of the measured data points for the sample irradiated under electrical bias while the shaded diamonds are the average of the measured data points for the units irradiated with all pins tied to ground. The black lines (solid or dashed) are the average of the data points after application of the KTL statistics on the sample irradiated in the biased condition while the shaded lines (solid or dashed) are the average of the data points after application of the KTL statistics on the sample irradiated in the unbiased condition. The red dotted line(s) are the pre- and/or post-irradiation minimum and/or maximum specification value as defined in the datasheet and/or test plan.

The control units, as expected, show no significant changes to any of the parameters. Therefore we can conclude that the electrical testing remained in control throughout the duration of the tests and the observed degradation was due to the radiation exposure.

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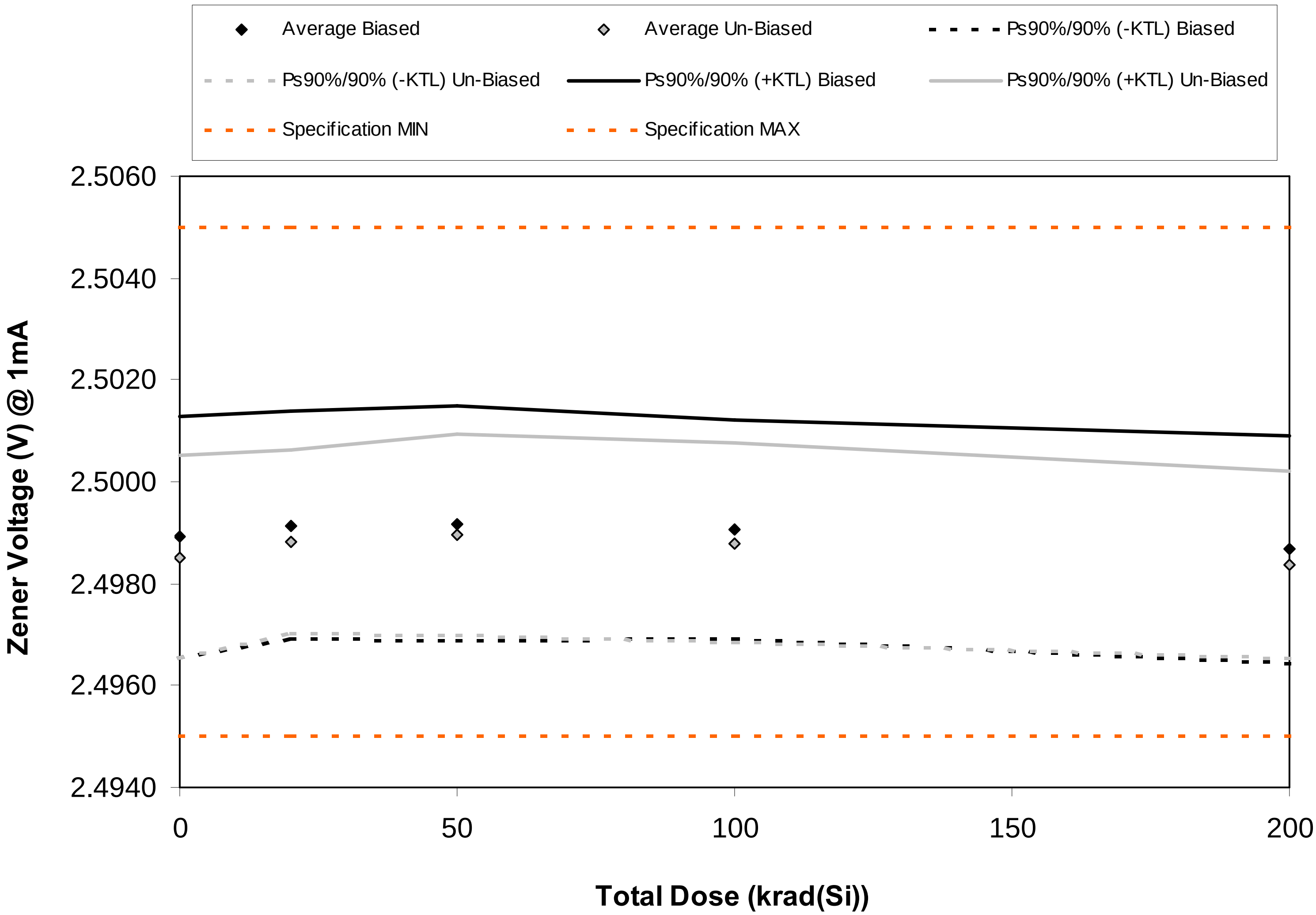

Figure 5.1. Plot of Zener voltage (reverse breakdown voltage) versus total dose. The data shows no significant degradation with radiation. The solid diamonds are the average of the measured data points for the sample irradiated under electrical bias while the shaded diamonds are the average of the measured data points for the units irradiated with all pins tied to ground. The black lines (solid or dashed) are the average of the data points after application of the KTL statistics on the sample irradiated in the biased condition while the shaded lines (solid or dashed) are the average of the data points after application of the KTL statistics on the sample irradiated in the unbiased condition. The red dotted line(s) are the pre- and/or post-irradiation minimum and/or maximum specification value as defined in the datasheet and/or test plan.

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Table 5.1. Raw data of the Zener voltage (reverse breakdown voltage) versus total dose, including the statistical analysis, the specification and the status of the testing (pass/fail).

Zener Voltage (V) @ 1mA	Total Dose (krad(Si))				
Device	0	20	50	100	200
1164	2.5000	2.5001	2.5002	2.5000	2.4997
1165	2.4989	2.4991	2.4992	2.4991	2.4988
1166	2.4978	2.4980	2.4980	2.4979	2.4975
1167	2.4993	2.4995	2.4995	2.4994	2.4990
1168	2.4995	2.4998	2.4998	2.4996	2.4991
1169	2.4980	2.4984	2.4984	2.4984	2.4979
1170	2.4983	2.4986	2.4988	2.4988	2.4985
1171	2.4990	2.4993	2.4994	2.4992	2.4987
1172	2.4992	2.4994	2.4996	2.4994	2.4989
1173	2.4976	2.4980	2.4980	2.4978	2.4974
1174	2.4982	2.4982	2.4983	2.4984	2.4984
1175	2.4987	2.4987	2.4987	2.4987	2.4988
Biased Statistics					
Average Biased	2.4989	2.4992	2.4992	2.4991	2.4987
Std Dev Biased	8.66E-04	8.17E-04	8.40E-04	7.84E-04	8.16E-04
Ps90%/90% (+KTL) Biased	2.5013	2.5014	2.5015	2.5012	2.5009
Ps90%/90% (-KTL) Biased	2.4965	2.4969	2.4969	2.4969	2.4964
Un-Biased Statistics					
Average Un-Biased	2.4985	2.4988	2.4990	2.4988	2.4984
Std Dev Un-Biased	7.27E-04	6.55E-04	7.19E-04	7.12E-04	6.70E-04
Ps90%/90% (+KTL) Un-Biased	2.5005	2.5006	2.5009	2.5008	2.5002
Ps90%/90% (-KTL) Un-Biased	2.4965	2.4970	2.4970	2.4968	2.4965
Specification MIN	2.4950	2.4950	2.4950	2.4950	2.4950
Status	PASS	PASS	PASS	PASS	PASS
Specification MAX	2.5050	2.5050	2.5050	2.5050	2.5050
Status	PASS	PASS	PASS	PASS	PASS

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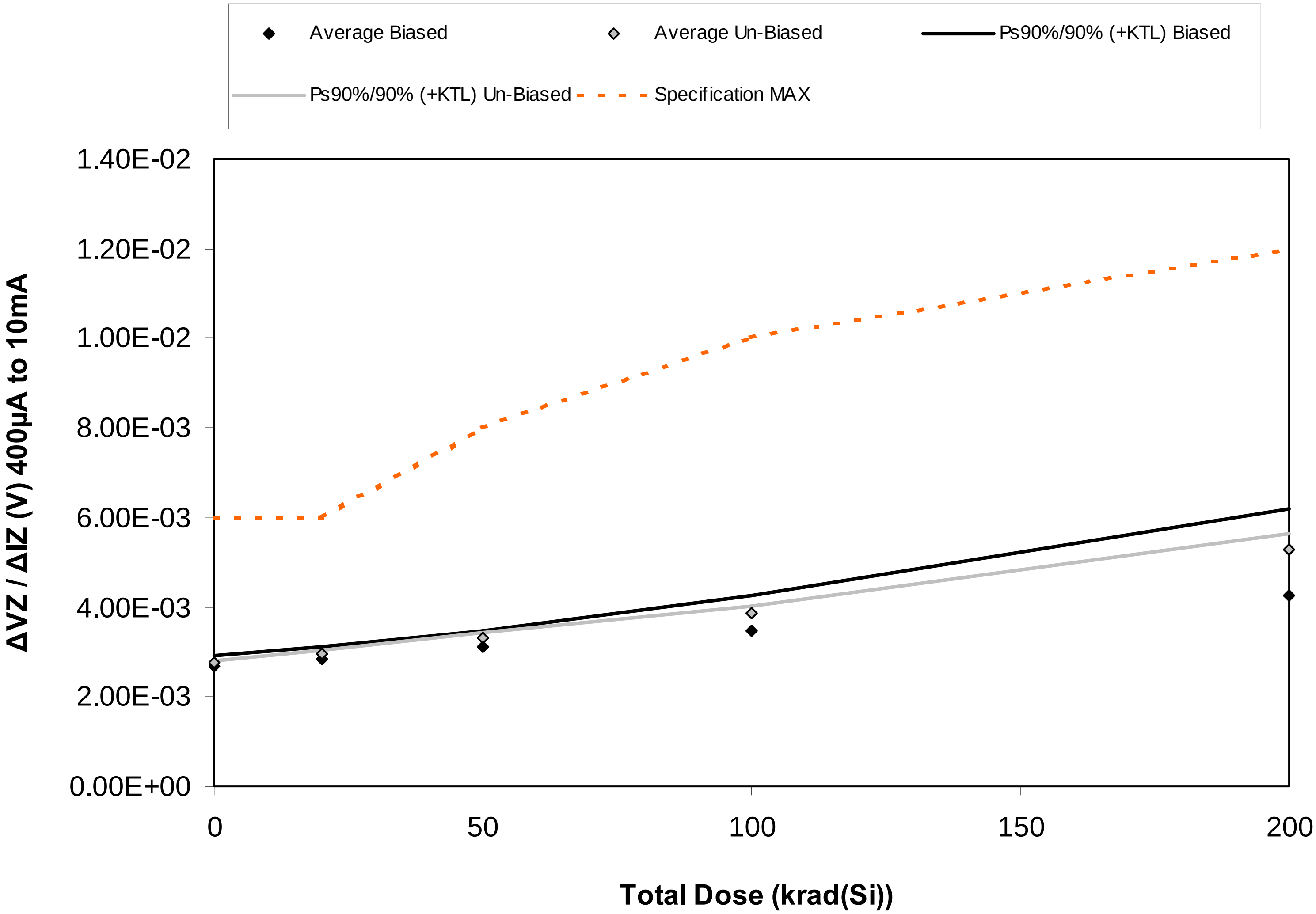

Figure 5.2. Plot of reverse breakdown voltage change with current versus total dose. The data show some increase with radiation, however it does not exceed the post-irradiation specification limit to the maximum tested total dose of 200krad(Si). The solid diamonds are the average of the measured data points for the sample irradiated under electrical bias while the shaded diamonds are the average of the measured data points for the units irradiated with all pins tied to ground. The black lines (solid or dashed) are the average of the data points after application of the KTL statistics on the sample irradiated in the biased condition while the shaded lines (solid or dashed) are the average of the data points after application of the KTL statistics on the sample irradiated in the unbiased condition. The red dotted line(s) are the pre- and/or post-irradiation minimum and/or maximum specification value as defined in the datasheet and/or test plan.

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Table 5.2. Raw data of the reverse breakdown voltage change with current versus total dose, including the statistical analysis, the specification and the status of the testing (pass/fail).

ΔVZ / ΔIZ (V) 400µA to 10mA	Total Dose (krad(Si))				
Device	0	20	50	100	200
1164	2.57E-03	2.67E-03	2.93E-03	3.23E-03	3.77E-03
1165	2.72E-03	2.83E-03	3.08E-03	3.37E-03	3.95E-03
1166	2.77E-03	2.87E-03	3.10E-03	3.46E-03	4.06E-03
1167	2.68E-03	2.79E-03	3.03E-03	3.37E-03	3.98E-03
1168	2.67E-03	2.84E-03	3.09E-03	3.47E-03	4.10E-03
1169	2.79E-03	2.97E-03	3.36E-03	4.03E-03	5.68E-03
1170	2.78E-03	2.94E-03	3.28E-03	3.91E-03	5.37E-03
1171	2.76E-03	2.92E-03	3.27E-03	3.78E-03	5.11E-03
1172	2.79E-03	2.98E-03	3.37E-03	3.90E-03	5.40E-03
1173	2.76E-03	2.92E-03	3.31E-03	3.90E-03	5.19E-03
1174	2.71E-03	2.58E-03	2.60E-03	2.59E-03	2.59E-03
1175	2.76E-03	2.71E-03	2.69E-03	2.68E-03	2.69E-03
Biased Statistics					
Average Biased	2.70E-03	2.83E-03	3.10E-03	3.49E-03	4.26E-03
Std Dev Biased	7.95E-05	9.85E-05	1.43E-04	2.79E-04	7.07E-04
Ps90%/90% (+KTL) Biased	2.92E-03	3.10E-03	3.49E-03	4.25E-03	6.19E-03
Ps90%/90% (-KTL) Biased	2.48E-03	2.56E-03	2.71E-03	2.72E-03	2.32E-03
Un-Biased Statistics					
Average Un-Biased	2.77E-03	2.94E-03	3.31E-03	3.87E-03	5.27E-03
Std Dev Un-Biased	1.50E-05	2.83E-05	4.50E-05	6.18E-05	1.40E-04
Ps90%/90% (+KTL) Un-Biased	2.81E-03	3.02E-03	3.43E-03	4.04E-03	5.65E-03
Ps90%/90% (-KTL) Un-Biased	2.73E-03	2.86E-03	3.18E-03	3.70E-03	4.88E-03
Specification MAX	6.00E-03	6.00E-03	8.00E-03	1.00E-02	1.20E-02
Status	PASS	PASS	PASS	PASS	PASS

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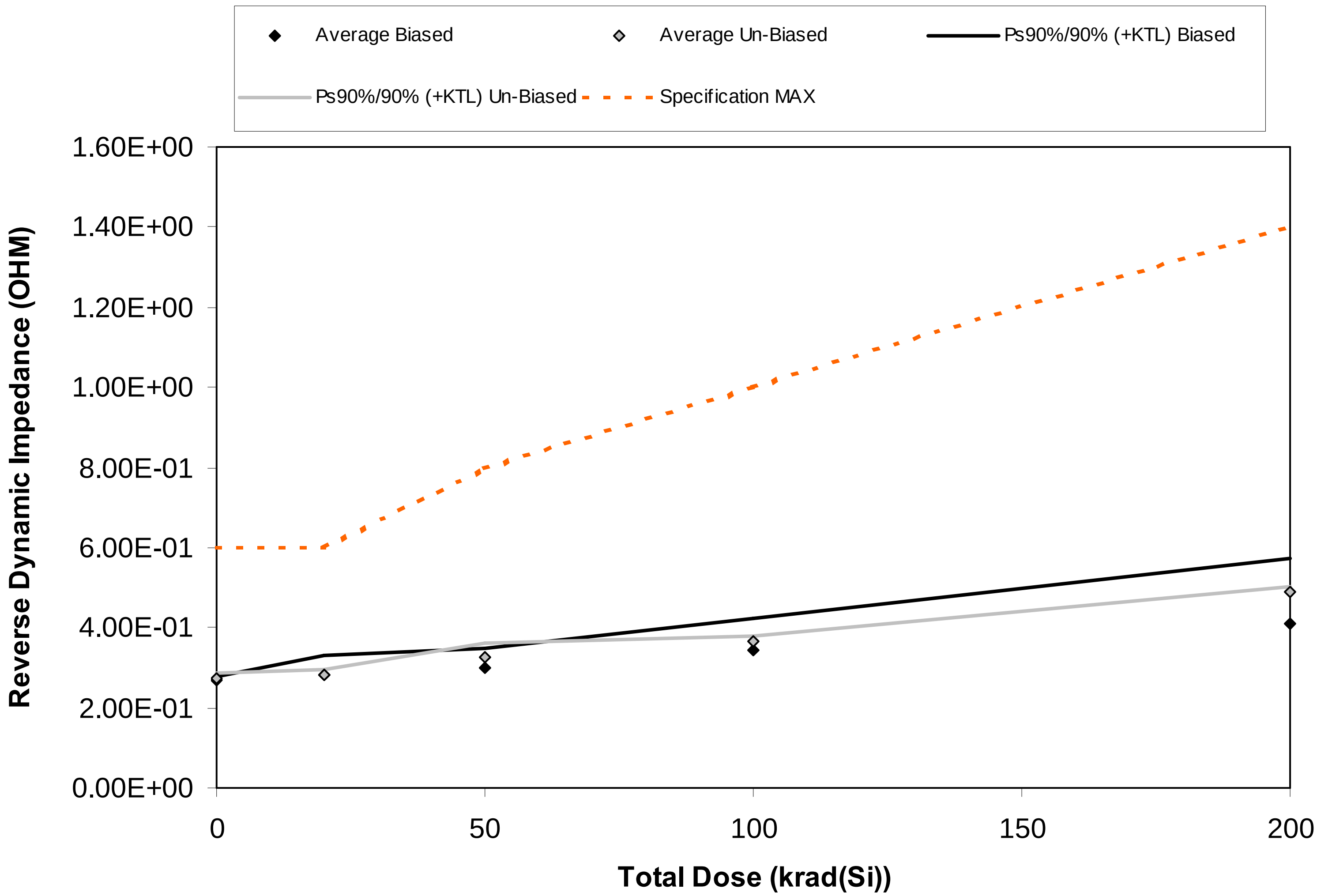

Figure 5.3. Plot of reverse dynamic impedance versus total dose. The data show some increase with radiation, however it does not exceed the post-irradiation specification limit to the maximum tested total dose of 200krad(Si). The solid diamonds are the average of the measured data points for the sample irradiated under electrical bias while the shaded diamonds are the average of the measured data points for the units irradiated with all pins tied to ground. The black lines (solid or dashed) are the average of the data points after application of the KTL statistics on the sample irradiated in the biased condition while the shaded lines (solid or dashed) are the average of the data points after application of the KTL statistics on the sample irradiated in the unbiased condition. The red dotted line(s) are the pre- and/or post-irradiation minimum and/or maximum specification value as defined in the datasheet and/or test plan.

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Table 5.3. Raw data of the reverse dynamic impedance versus total dose, including the statistical analysis, the specification and the status of the testing (pass/fail).

Reverse Dynamic Impedance (OHM)	Total Dose (krad(Si))				
Device	0	20	50	100	200
1164	2.60E-01	2.60E-01	2.80E-01	3.20E-01	3.70E-01
1165	2.70E-01	2.70E-01	3.00E-01	3.30E-01	3.80E-01
1166	2.70E-01	2.90E-01	3.10E-01	3.40E-01	3.90E-01
1167	2.70E-01	2.80E-01	2.90E-01	3.30E-01	3.80E-01
1168	2.70E-01	2.70E-01	3.00E-01	3.40E-01	4.00E-01
1169	2.70E-01	3.10E-01	3.30E-01	4.00E-01	5.30E-01
1170	2.70E-01	2.80E-01	3.20E-01	3.70E-01	4.90E-01
1171	2.70E-01	2.80E-01	3.10E-01	3.60E-01	4.90E-01
1172	2.80E-01	2.90E-01	3.40E-01	3.70E-01	4.90E-01
1173	2.70E-01	2.80E-01	3.30E-01	3.70E-01	4.80E-01
1174	2.70E-01	2.60E-01	2.60E-01	2.70E-01	2.70E-01
1175	2.70E-01	2.60E-01	2.70E-01	2.60E-01	2.60E-01
Biased Statistics					
Average Biased	2.68E-01	2.80E-01	3.02E-01	3.43E-01	4.08E-01
Std Dev Biased	4.08E-03	1.79E-02	1.72E-02	2.88E-02	6.05E-02
Ps90%/90% (+KTL) Biased	2.80E-01	3.29E-01	3.49E-01	4.22E-01	5.74E-01
Ps90%/90% (-KTL) Biased	2.57E-01	2.31E-01	2.54E-01	2.64E-01	2.43E-01
Un-Biased Statistics					
Average Un-Biased	2.73E-01	2.83E-01	3.25E-01	3.68E-01	4.88E-01
Std Dev Un-Biased	5.00E-03	5.00E-03	1.29E-02	5.00E-03	5.00E-03
Ps90%/90% (+KTL) Un-Biased	2.86E-01	2.96E-01	3.60E-01	3.81E-01	5.01E-01
Ps90%/90% (-KTL) Un-Biased	2.59E-01	2.69E-01	2.90E-01	3.54E-01	4.74E-01
Specification MAX	6.00E-01	6.00E-01	8.00E-01	1.00E+00	1.40E+00
Status	PASS	PASS	PASS	PASS	PASS

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6.0. Summary / Conclusions

The total ionizing dose testing described in this final report was performed using the facilities at Radiation Assured Devices' Longmire Laboratories in Colorado Springs, CO. The high dose rate total ionizing dose (TID) source is a JLSA 84-21 irradiator modified to provide a panoramic exposure. The Co-60 rods are held in the base of the irradiator heavily shielded by lead, during the radiation exposures the rod is raised by an electronic timer/controller and the exposure is performed in air. The dose rate for this irradiator in this configuration ranges from <1rad(Si)/s to a maximum of approximately 120rad(Si)/s, determined by the distance from the source.

The parametric data was obtained as "read and record" and all the raw data plus an attributes summary were presented in this report. The attributes data contains the average, standard deviation and the average with the KTL values applied. The KTL value used was 2.742 per MIL HDBK 814 using one-sided tolerance limits of 90/90 and a 5-piece sample size. Note that the following criteria was used to determine the outcome of the testing: following the radiation exposure each parameter had to pass the specification value and the average value for the five-piece sample must pass the specification value when the KTL limits are applied. If these conditions were not both satisfied following the radiation exposure, then the lot would be logged as an RLAT failure.

Based on these criteria, the RH1009 2.5V voltage reference PASSED the RLAT to the maximum tested total dose of 200krad(Si) with no significant degradation to any of the measured parameters.

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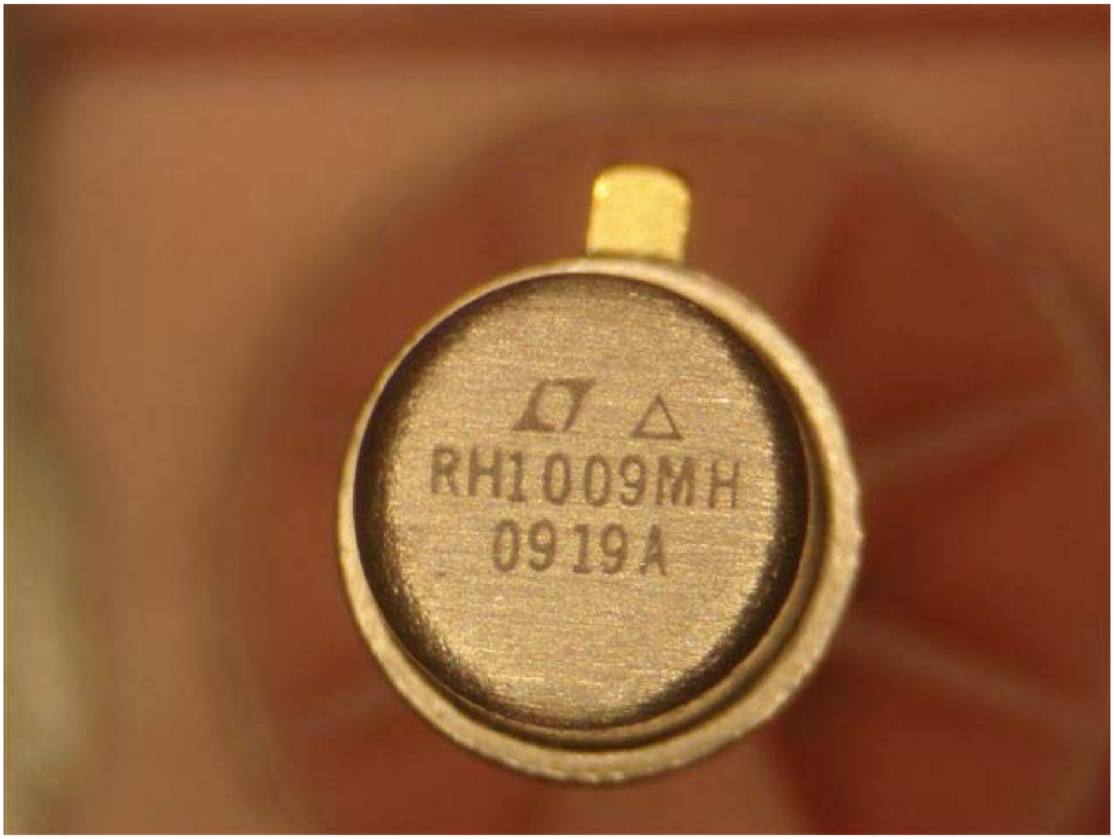
Appendix A: Photograph of device-under-test to show part markings



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Appendix B: TID Bias Connection Tables

(Extracted from LINEAR TECHNOLOGY CORPORATION RH1009 Datasheet)

Biased Samples:

Function	Bias
V+	To +15V via 12.4kΩ Resistor
ADJ	N/C
V-	GND

Unbiased Samples (All Pins Tied to Ground):

Function	Bias
V+	GND
ADJ	GND
V-	GND

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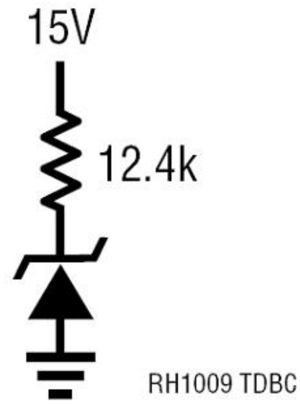

Figure B.1. Irradiation bias circuit for the units to be irradiated under electrical bias. This figure was extracted from the LINEAR TECHNOLOGY CORPORATION RH1009 Datasheet.

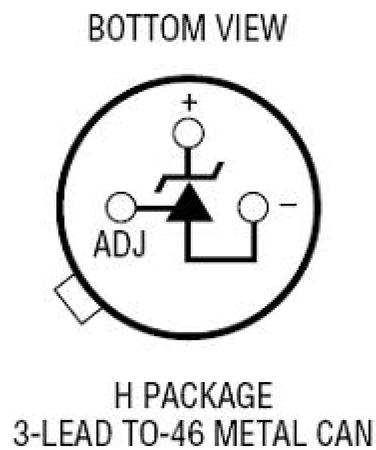

Figure B.2. H package drawing (for reference only). This figure was extracted from the LINEAR TECHNOLOGY CORPORATION RH1009 Datasheet.

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Appendix C: Electrical Test Parameters and Conditions

All electrical tests for this device are performed on one of Radiation Assured Device's LTS2020 Test Systems. The LTS2020 Test System is a programmable parametric tester that provides parameter measurements for a variety of digital, analog and mixed signal products including voltage regulators, voltage comparators, D to A and A to D converters. The LTS2020 Test System achieves accuracy and sensitivity through the use of software self-calibration and an internal relay matrix with separate family boards and custom personality adapter boards. The tester uses this relay matrix to connect the required test circuits, select the appropriate voltage / current sources and establish the needed measurement loops for all the tests performed. The measured parameters and test conditions are shown in Table C.1.

A listing of the measurement precision/resolution for each parameter is shown in Table C.2. The precision/resolution values were obtained either from test data or from the DAC resolution of the LTS-2020. To generate the precision/resolution shown in Table C.2, one of the units-under-test was tested repetitively (a total of 10-times with re-insertion between tests) to obtain the average test value and standard deviation. Using this test data MIL-HDBK-814 90/90 KTL statistics were applied to the measured standard deviation to generate the final measurement range. This value encompasses the precision/resolution of all aspects of the test system, including the LTS2020 mainframe, family board, socket assembly and DUT board as well as insertion error. In some cases, the measurement resolution is limited by the internal DACs, which results in a measured standard deviation of zero. In these instances the precision/resolution will be reported back as the LSB of the DAC.

Note that the testing and statistics used in this document are based on an "analysis of variables" technique, which relies on small sample sizes to qualify much larger lot sizes (see MIL-HDBK-814, p. 91 for a discussion of statistical treatments). Unfortunately, not all measured parameters are well suited to this approach due to inherent large variations. If necessary, larger samples sizes could be used to qualify these parameters using an "attributes" approach.

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Table C.1. Measured parameters and test conditions for the RH1009MH. Unless otherwise noted the conditions were selected to match the post-irradiation specifications. See LINEAR TECHNOLOGY CORPORATION RH1009 Datasheet for the post irradiation test conditions and specifications.

Parameter	Test Conditions
Reverse Breakdown Voltage, V_Z (V)	I_R=1mA
Reverse Breakdown Voltage Change wiht Current, $\Delta V_Z / \Delta I_Z$ (V)	I_R=400µA to I_R=10mA
Reverse Dynamic Impedence. RZ (Ω)	I_R=1mA

Table C.2. Measured parameters, pre-irradiation specifications and measurement resolution for the RH1009MH.

Measured Parameter	Pre-Irradiation Specification	Measurement Precision/Resolution
Reverse Breakdown Voltage, V_Z (V)	2.495-2.505V	±1.74E-04V
Reverse Breakdown Voltage Change wiht Current, $\Delta V_Z / \Delta I_Z$ (V)	6mV MAX	±3.20E-05V
Reverse Dynamic Impedence. RZ (Ω)	0.6Ω MAX	±1E-02 Ω