

Continuing Evaluation of Bipolar Linear Devices for Total Dose Bias Dependency and ELDRS Effects

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Abstract-- We present results of continuing efforts to evaluate total dose bias dependency and ELDRS effects in bipolar linear microcircuits. Several devices were evaluated, each exhibiting moderate to significant bias and/or dose rate dependency.

I. INTRODUCTION

STANDARD linear bipolar microcircuits continue to be used in a variety of space applications with total dose radiation requirements. Many of these devices have a significant amount of flight history, others are just beginning to be used or are proposed for use. In either case, these devices have often not been completely characterized for dose rate and bias effects in the total dose environment. It has been known for some time that bipolar linear devices often perform worse at dose rates lower than those that have been typically used in laboratory tests [1]-[3]. This effect has been termed Enhanced Low Dose Rate Sensitivity (ELDRS) with the physical mechanisms for this effect being proposed in [4]-[6], as well as others. It has further been shown that these devices can be sensitive to the bias condition during irradiation [7]-[8]. Understanding device sensitivity to bias and dose rate under irradiation is critical for bounding device performance for space applications as the actual dose rate is

typically very low and devices may be in a variety of bias conditions for the mission duration.

Reported herein are the results from tests, which were performed as a continuing effort to evaluate bipolar linear devices for both bias and dose rate effects. The objective in most cases is to determine whether the typical biased or unbiased condition represents the worst-case condition during irradiation and to determine if the device is susceptible to ELDRS. It should be noted, however, that these tests were not intended to provide an upper bound, or worst case, for device parameter performance. It has been shown [9] that some devices perform worse at dose rates lower than those used in these tests. Further, it is not possible, to test all possible bias conditions to ensure a worst case.

II. DEVICE DESCRIPTIONS

Results from total dose characterization tests of six different device types from different manufacturers are included herein. Part numbers and lot identification for the devices tested are provided in Table I. All devices were obtained directly from the manufacturer and procured as lots intended for flight use. All of the devices were fabricated on the manufacturer's standard bipolar process.

III. EXPERIMENTAL DETAILS

A. Total Dose Facilities

Total dose irradiations for the LT1006, LT1963, and LM3940 were performed at the high and low dose rate (HDR and LDR) Co-60 range sources at the Jet Propulsion Laboratory, Pasadena, CA. These facilities each have a Shepherd Co-60 irradiator that irradiates into an open vault. Total dose irradiations for the LM158's, National and Motorola, were performed at the Raytheon Component Evaluation Center, El Segundo CA, under the direction of Boeing Satellite Systems. At this facility, low and high dose rate irradiations were performed using a Shepherd model 142 Co-60 and a Gammacell 220 Co-60 irradiator respectively. The Shepherd 142 had a 'pencil' cobalt source in the center of a cylindrical chamber. In this configuration dose rate is adjusted by changing distance from the source. Total dose irradiations for the LM136 were performed at the Boeing Radiation Effects Laboratory, Seattle WA. Low and high

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TABLE I
IDENTIFICATION OF TESTED PART TYPES

Generic	Part Number	Date Code (diffusion)	Die Manufacturer	Description	Procured as
LT1006A	5962-8993302GA	9626A	Linear Technology	Precision Op-Amp	B-level, hermetic TO-5
LM136	5962-0050101QXA	(199923494)	National	2.5V shunt regulator diode	B-level, hermetic TO-5
LM158	5962-8771001GA	9819 and 0234	National	Dual Op-Amp	B-level, hermetic TO-5
LM158	5962-8771001GA	(6211W)	Motorola	Dual Op-Amp	B-level, hermetic TO-5
LT1963	LT1963ES8	0105	Linear Technology	1.5A Adjustable LDO Regulator	Plastic SOIC
LM3940	5962-9688401QXA	0111	National	1.5A, 3.3V LDO Regulator	Q-level, hermetic SMD

dose rate irradiations at this facility were performed using a Shepherd 484 Co-60 irradiator and the Gamma Vault facility respectively. Dose rates for the high dose rate exposures ranged between 25 to 150 rad/s. Low dose rate exposures were carried out at between 0.01 to 0.02 rad/s. All sources were in compliance with MIL-STD-883, Method 1019, and have undergone dosimetry correlation [10].

B. Electrical Tests

All electrical tests for parts tested at Raytheon in El Segundo, CA, were performed using an LTX mixed signal automated test system. Electrical tests for parts tested at JPL and BREL were performed using an LTS2020 mixed signal automated test system. Irradiations and electrical tests for each device type were performed at the same location. Electrical tests included, as a minimum, all of the DC test parameters in the manufacturer's specification. In exception to this, the LM3940 was monitored for V_{out} on the bias card only.

C. Procedure

Samples of each device type were divided into four groups of five parts each for biased and unbiased low rate as well as biased and unbiased high rate irradiations. Exception to this was the LM158 from National, where there was no biased testing done. After pre-irradiation electrical tests, the four groups underwent step level irradiation and test. The time between irradiation steps for electrical tests was between one to two hours. The outputs of the biased samples were periodically monitored on the bias circuit to ensure that the devices were stable while under irradiation. The time frame for group tests for each device type was maintained as short as possible; i.e. months did not pass between high and low dose rate tests. This was done to minimize any error due to equipment calibration changes. The irradiation bias conditions for biased irradiations are defined in Table II. Parts in the unbiased groups had all leads shorted.

TABLE II
IRRADIATION BIAS CONDITIONS

Device	Bias conditions
LT1006	$V_{cc} = 30V$, $V_{ee} = 0$, $V_{cm} = 10V$, voltage follower
LM136	$I_r = 1mA$, $V_z = 2.5V$
LM158	$V_+ = +15V$, $V_- = -15V$, $V_{cm} = 0$, Voltage follower
LT1963	$V_{in} = 6V$, $V_{out} = 5V$, $I_{out} =$ $100mA$, $V_{sd} = 6V$
LM3940	$V_{in} = 5V$, $I_{out} = 100mA$

IV. TEST RESULTS

A. LT1006A

The LT1006 exhibited a significant ELDRS effect and some bias dependency. Most effected parameter was the input bias current, I_b , which drifted 8 to 10 times more for the low dose rate cases (Fig. 1). Although no bias dependency is seen for I_b in the low rate case, the device appeared to fail functionally for the biased high dose rate condition at 10 to 15 Krad. Input offset voltage (Fig. 2) exhibited both dose rate and bias dependency with the biased low rate condition demonstrating the worst-case degradation. Again, though the low dose rate cases exhibited the worst parametric degradation, the device was observed to fail functionally after 10 Krad. This functional failure is likely due to rapid build up of oxide trapped charge leading to significant internal leakage in the device. Though not shown this was evident in a large increase in supply current after 15 Krad. As evident from the low dose rate test groups this failure mode is not likely to occur at the low dose rate of space applications.

B. LM136

Reference voltage for the LM136 device exhibited both a significant and bias effect although the device specification, $\pm 50\text{mV}$ was not exceeded to the levels tested (Fig. 3). The low dose rate case was worse for both bias conditions with about a 5 times parametric enhancement factor at 30 Krad. The unbiased case was significantly worse than the biased case for both high and low dose rate.

C. LM158

Samples of the LM158 dual op-amp were obtained from both National Semiconductor and Motorola Semiconductor to evaluate both devices for dose rate and bias dependency and to compare the performance of the two. For both manufacturers' devices, input bias current was the most sensitive parameter. For the Motorola device only a minor ELDRS effect is evident (Fig. 4) to the levels tested and a minor bias dependency is found for the low rate case only. In contrast, a fairly moderate ELDRS effect is evident for the National Semiconductor device (Fig. 5). For the National device input bias current exhibits an enhancement factor of about 3. The biased case was not tested for this device due to a limited availability of test samples.

D. LT1963

The most sensitive parameter for the LT1963 voltage regulator was found to be the dropout voltage that exceeded specification under 5 Krad. This parameter indicated only a minor ELDRS effect up to 15 Krad (Fig. 6). However, above 15 Krad devices in the low dose rate unbiased group failed to drive the required 1A load. This functional failure is likely due to loss of gain in the lateral PNP pass transistor; an ELDRS and bias sensitive failure mode found in previous tests [11].

E. LM3940

The National LM3940 was found to be both bias and dose rate sensitive (Fig. 7) with the biased low dose rate case exhibiting the most significant degradation. Here the device output voltage at 1A is found to fall rapidly with failure to the specification occurring at about 5 Krad for the biased low dose rate case. In contrast, when tested at high dose rate the device continues to be within specification to 15 Krad while biased. It is not known in this case if the failure mechanism is in the reference circuit or the pass transistor since V_{out} was only observed for one load condition

V. DISCUSSION

To varying degrees, all of the devices tested exhibited enhanced low dose rate sensitivity with the low dose rate test condition generally resulting in more parametric degradation than the high dose rate case. Whether the biased or unbiased condition represented the worst case with respect to radiation was dependent on the device type and the specific parameter.

VI. CONCLUSIONS

It is clear from these and previous test results that complete characterization of bipolar linear microcircuits should include testing in both the biased and unbiased conditions as well as at multiple dose rates to determine ELDRS susceptibility.

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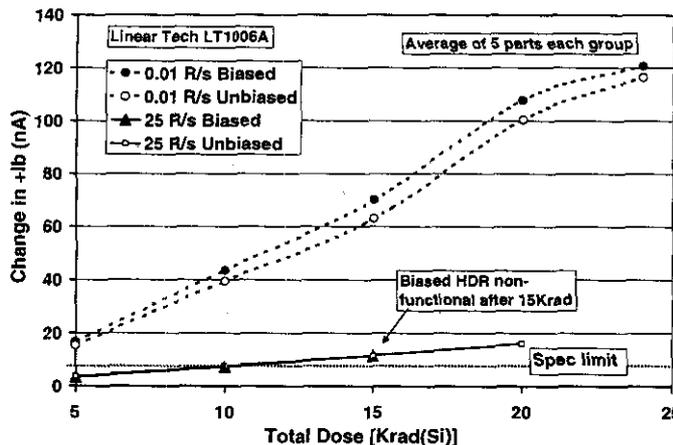


Fig. 1. Input bias current for the LT1006 exhibited ELDRS with no bias effect for the low dose rate case.

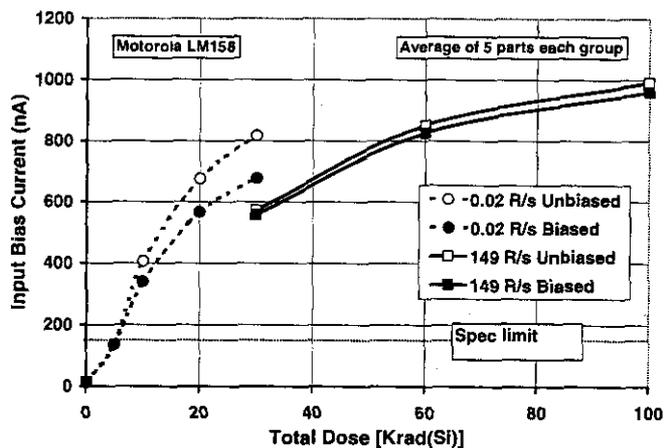


Fig. 4. The Motorola LM158 exhibits only a minor ELDRS effect. A minor bias dependency is seen for the low dose rate case.

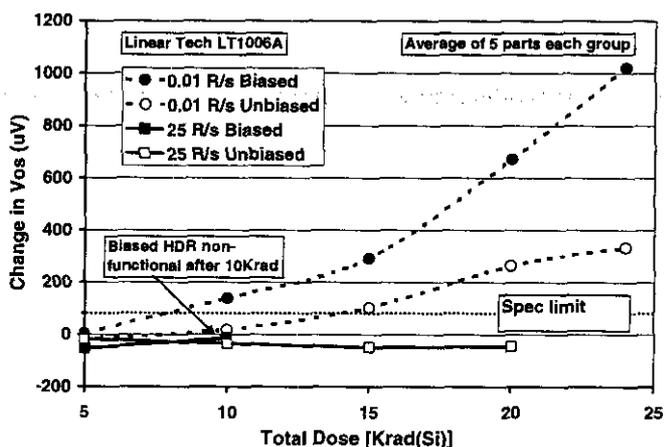


Fig. 2. Input offset voltage for the LT1006 exhibited both ELDRS and bias effects.

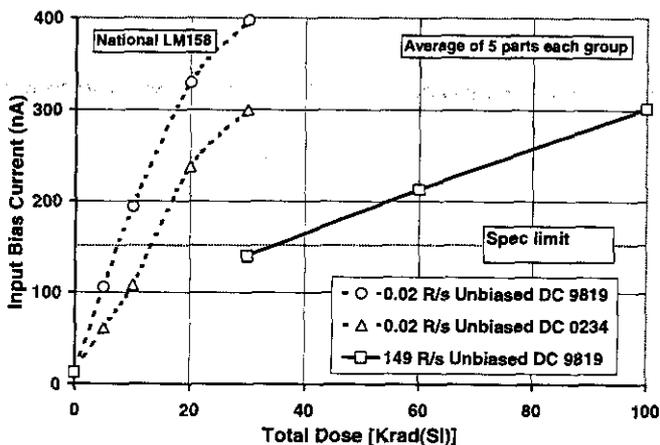


Fig. 5. The National LM158 exhibits a moderate ELDRS effect with input bias current degrading about a factor of three worse at low dose rate.

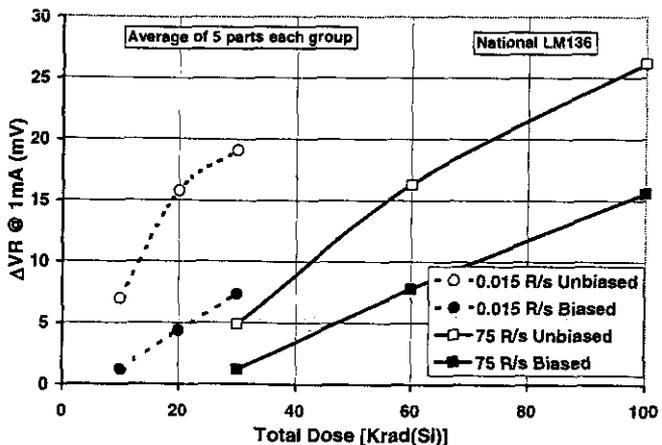


Fig. 3. LM136 reference voltage exhibited more change for the low dose rate and the unbiased cases.

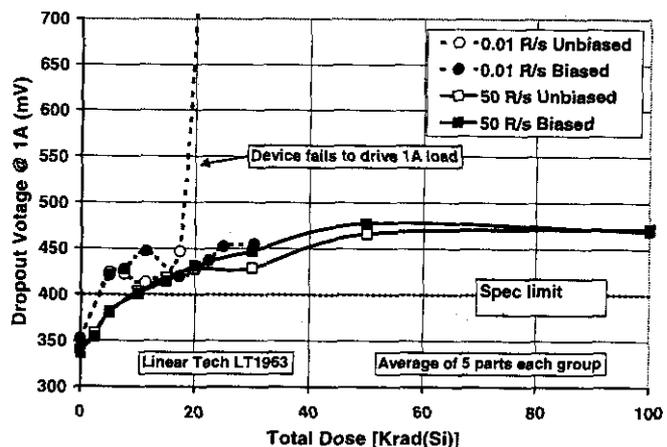


Fig. 6. Dropout voltage for the LT1963 seems to have only a minor ELDRS effect below 15 Krad. However the low dose rate unbiased case fails to drive the require load current above 15 Krad.

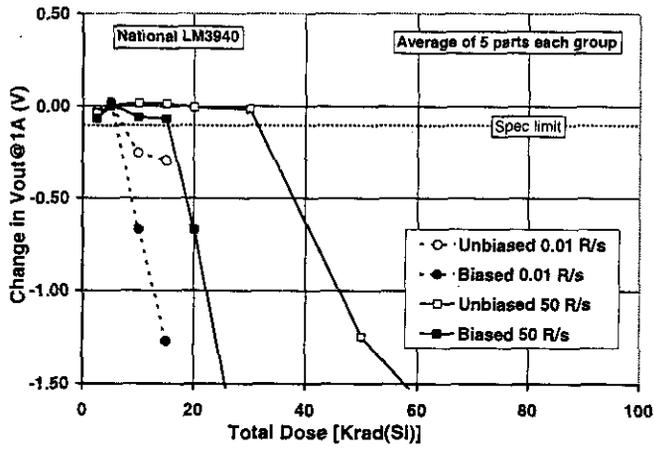


Fig. 7. Output voltage for the LM3940 exhibited pronounced ELDRS and bias sensitivity with the biased low rate case having the most significant degradation.