Continuing Radiation Evaluation of Commercial-Off-The-Shelf Devices for Space Applications

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ABSTRACT—Radiation test results are presented for a number of commercial transistors and integrated circuits procured in both ceramic and plastic packages. This is part of an ongoing evaluation of the suitability of commercial-off-the-shelf devices for space applications.

I. INTRODUCTION

IN 1998, a project was instituted at Hughes to look at nontraditional parts as replacements for existing hi-rel space qualified parts. Several devices procured as off-the-shelf parts, packaged in plastic, were evaluated for radiation sensitivity and nonradiation concerns [1]. Additional devices in both hermetic and plastic packages have since been radiation-characterized to determine their suitability for space use. The devices considered include alternates to existing parts and new devices for new designs.

Samples of 10 devices, five transistors (four bipolar and one MOSFET) and five integrated circuits (a voltage regulator, a regulator controller, an EEPROM, a decoder, and a latch), were procured for evaluation. These devices were bought as commercial-grade parts with no special handling or third-party packaging or testing.

Testing of potential replacements for existing devices (such as the 2N2222A) was done using the same conditions, biasing, and dose rate as is currently used for radiation lot acceptance testing on the same parts procured as hi-rel versions. The only variance was that devices were tested with and without burn-in to assess the effects of elevated temperature processing. (See references 2–6 for a discussion of burn-in effects.) All test samples for all device types were from recent production, date codes 99XX or 00XX. Sample sizes for each test varied from 5–10 parts.

The linear integrated circuits were subjected to high (40–69 rad/sec) and low (0.01–0.06 rad/sec) dose rate exposures, with and without bias (see Table I). This was done to determine if the devices exhibited enhanced low dose rate sensitivity (ELDRS). The Hitachi EEPROM was exposed at low dose rate to see if one could realize improved performance. The EEPROM was also subjected to a rebound test per MIL-STD-883, method 1019.

II. RADIATION TESTING

A. Test Conditions

The radiation testing consisted of a step level, multi-parameter test. Exposures were conducted with a cobalt-60 source in accordance with either MIL-STD-750 or MIL-STD-883, method 1019. The high dose rate testing was between 40 and 69 rad/sec with electrical testing commencing within minutes of the termination of exposure. In addition, the two linear integrated circuits were also exposed at low dose rates (~0.01 or 0.06 rad/sec). Electrical testing of the transistors was done on an Eaton Impact III. The integrated circuits were tested on an LTX. The devices that were low dose rate tested were both biased and unbiased (grounded) during exposure. See Table I for a summary of test conditions.

All of the ICs were subjected to burn-in or bake (125°C, 168 hours) prior to testing. The uC1836 was also tested with no preconditioning. The test samples for the transistors were split into two groups. The first set was tested as supplied by the manufacturer; no additional screening or preconditioning was done. The second group of samples was subjected to a standard 168 hour, 125°C burn-in using the manufacturer's recommended circuitry.

B. Test Results

1) Transistors

Degradation of the 2222 and 2907 transistors was very small in comparison to results obtained on hi-rel parts from other manufacturers. Degradation on I_{cbo} and V_{ce}(sat) was minimal. Gain showed significantly less degradation than our current derating guidelines (see Figs. 1 and 2). The 2222 showed no burn-in effects. The 2907 exhibited a slight difference. This is in contrast to what has been seen on the same parts from other manufacturers [1, 5].

The BC856, which is similar to the 2N4029, also behaved well compared to hi-rel versions of the 4029. Lot-to-lot variation was greater than with the 2222 but still small compared to what we have seen on hi-rel parts.

The BC846 behaved well up to 100 krad; at higher levels we saw anomalous behavior. It is not clear if this is a test or

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TABLE I
COTS RADIATION TEST SUMMARY

P/N (Part Type)	Bias During* Exposure	Vendor	Package	Preconditioning/ Dose Rate	Rad Results
MMBT2222 (NPN)	Vce = 45V	General Semiconductor (GS)	Plastic, SOT-23	None and burned-in/ 50 rad/sec	Little burn-in sensitivity. Device degradation was small compared to other manufacturers' parts (see Fig. 1). Three lots tested.
MMBT2907 (PNP)	Vce = 0	GS	Plastic, SOT-23	None and burned-in/ 50 rad/sec	Similar results to the 2222. Very little degradation relative to our current guideline. Slight burn-in effect (see Fig. 2).
BC846B (NPN)	Vce = 45V	GS	Plastic, SOT-23	None and burned-in/ 50 rad/sec	Anomalous behavior above 100 krad, otherwise similar to performance to other transistors from GS.
BC856B (PNP)	Vce = 0 and –45V	GS	Plastic, SOT-23	None and burned-in/ 50 rad/sec	Less degradation than hi-rel equivalent. Greater lot-to-lot spread than the 2222s, but still fairly tight.
IRL2910 (MOSFET)	Vds = 80V and Vgs = 12V	International Rectifier (IR)	Plastic, SOT-23	None/ 50 rad/sec	Significant bias dependency. Failures above 10 krad in gate bias mode.
LT1528 (Voltage regulator)	V = 0, 15V	Linear Technology	Plastic, DD package	Baked/ 0.06 and 40 rad/sec	Significant dose rate effects, but little bias dependency (see Figs. 3 and 4).
uC1836 (Controller)	V = 0, 15V	Unitrode	Ceramic	None, baked/ 0.01 and 40 rad/sec	Shows both some bias and dose rate dependency (see Figs. 5 and 6).
58C1001 (EEPROM)	V = 0, 5V	Hitachi	Ceramic flatpack	Baked/ 0.04 and 50 rad/sec	Exhibits both bias and dose rate dependency. Approximately 10 times harder at low dose rates.
74LVC138 (Decoder)	V = 3.3V	Philips, Fairchild	Plastic, TSSOP	Baked/ 50 rad/sec	Icc increases. Functional to 200 krad; some annealing. See Fig. 7.
74LVC373 (Latch)	V = 3.3V	Philips, Fairchild	Plastic, TSSOP	Baked/ 69 rad/sec	Functional failures at 60 krad at low voltage. Functional to 200 krad at higher voltage. Ioxzh and Voh failures.

*Transistors were either reverse-biased during exposure (Vce = 45V) and/or leads were grounded (V = 0V).
Linears were similarly either grounded (V = 0) or biased using the vendor burn-in circuit (V = 5 or 15V, see above).

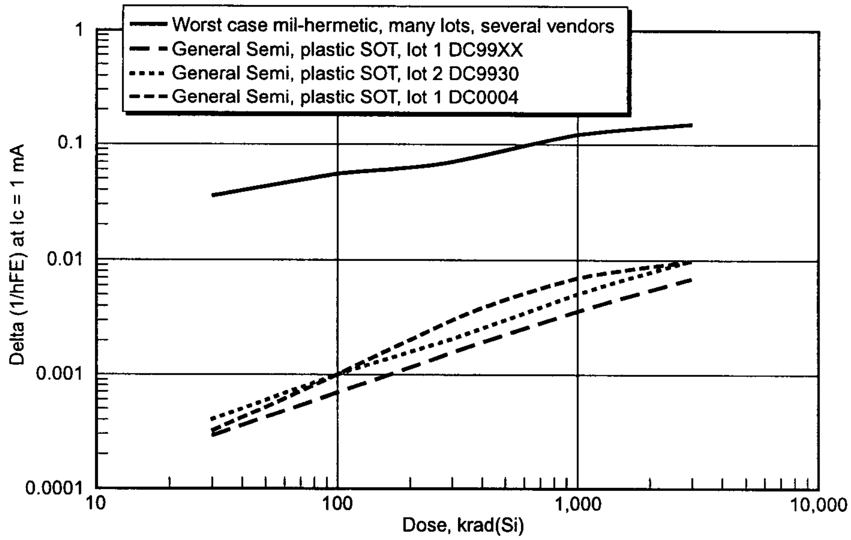

Figure 1. MMBT2222 Gain Degradation

part problem. All the other General Semiconductor (GS) parts (three different part types, eight different lots) behaved normally. More testing on a new lot needs to be done.

These devices are produced on a very high-volume commercial line. They are ion implanted and subject to statistical process control. The small lot-to-lot variation shows what is possible on a high-volume, well-controlled commercial line. The relatively small degradation is more serendipitous.

The IRF2910 exhibited significant bias dependency. When statically biased across the gate, the devices went into depletion at 20 krad. When biased across the drain, the devices remained in enhancement mode out to 100 krad; however, even in this mode, leakages began to rise significantly above 30 krad. Additional testing with a switching bias is planned.

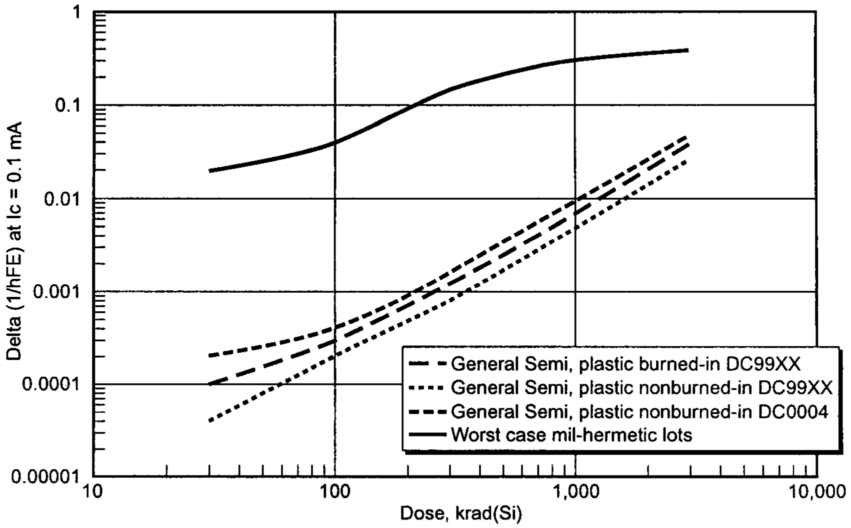

Figure 2. MMBT2907 Gain Degradation

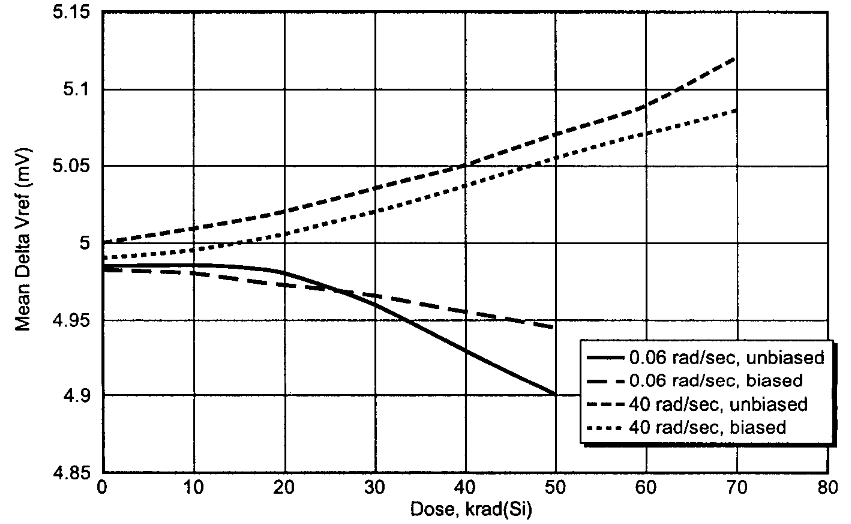

Figure 3. LT1528 Radiation Degradation

2) Integrated Circuits

The LT1528 exhibited ELDRS (see Figs. 3 and 4). This was evident primarily in the reference voltage shift and maximum output current. Little bias dependency was observed, unlike other low dropout voltage regulators previously reported on [6, 7]. This may have been due to the low current (100 mA) for the biased case. The device is capable of 3A output current.

The uC1836 was supplied to us with two different passivations, 7000Å of oxide and 2000Å nitride over a 7 kÅ oxide layer. The oxide passivation shows significantly less shift (Fig. 5) than the nitride passivation (Fig. 6). The nitride devices showed no sensitivity to a prebake, while the oxide passivation showed a slight difference. Conversely, the nitride passivated devices showed a significant bias dependency at high and low dose rates. The oxide showed no bias variation at high dose rates and slight variation at low dose rates. The nitride parts showed a significant dose rate enhancement for the biased case but virtually none for unbiased parts.

The Hitachi 58C1001 EEPROM showed both significant bias and dose rate dependency. When irradiated in a biased read mode at 50 rad/sec, device failure for read and write modes was below 30 and 20 krad(Si), respectively. When irradiated unbiased at 50 rad/sec, no failures were observed out to the highest exposure level, 200 krad(Si). This suggests that failures found for the biased case are due to read and write circuitry rather than the memory array itself. Similar results have been previously reported. Retest of the biased condition at low dose rate (0.04 rad/sec) found that read and write failures did not occur until above 200 krad(Si).

The low voltage CMOS devices (74LVC series) functioned and remained in spec almost to 200 krad (see Fig. 7). However, lowering the supply voltage led to functional failures at lower levels.

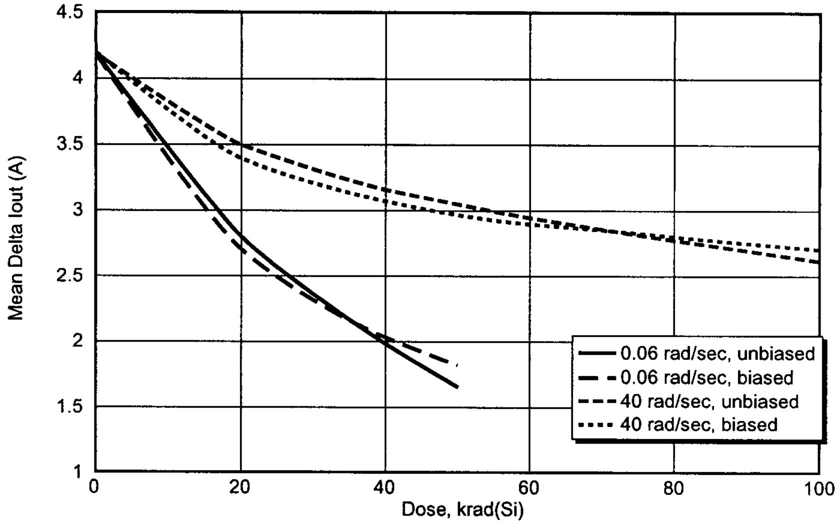

Figure 4. LT1528 Radiation Degradation

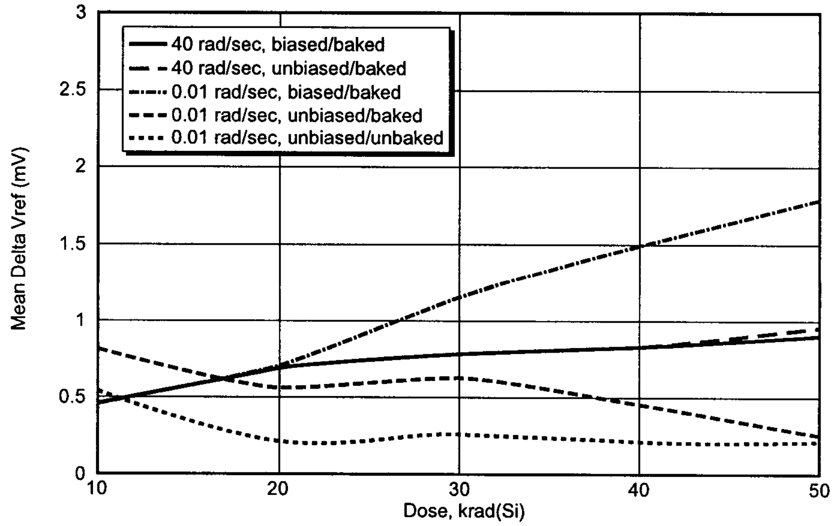

Figure 5. uC1836–Oxide Passivation Radiation Degradation

III. CONCLUSIONS/RECOMMENDATIONS

The bipolar transistors tested in this study exhibited significantly less radiation degradation than comparable hi-rel hermetic parts and plastic parts [1] from other vendors. Additional nonradiation testing [1] is in process so that these parts can be fully qualified for space use.

The MOSFET was significantly more sensitive than comparable radiation-hardened devices currently available. Its sensitivity was extremely bias-dependent. Such parts could be used in selected applications but are not suitable as universal replacements for hardened devices.

Results on the integrated circuits varied. The voltage regulator exhibits significant enhancement at low dose rate. With some shielding, all the devices could be used in the natural space environment for most orbits.

While little to no burn-in effect was seen on any of the parts in this test, it is recommended that any characterization of a new part include thermal preconditioning.

These results show that selected COTS parts can be used in space applications but definitely need to be fully characterized for both dose rate and bias dependency. Potential lot-to-lot variation must also be considered. Testing of at least several different lots is recommended.

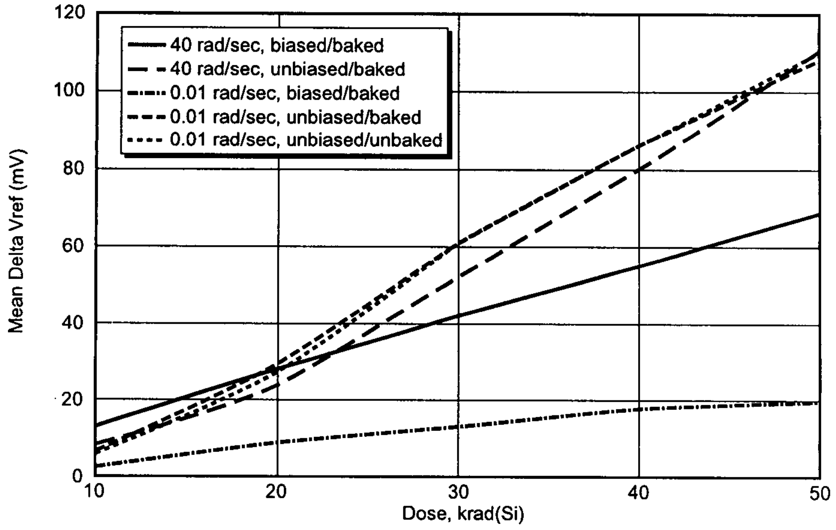

Figure 6. uC1836–Nitride Passivation Radiation Degradation

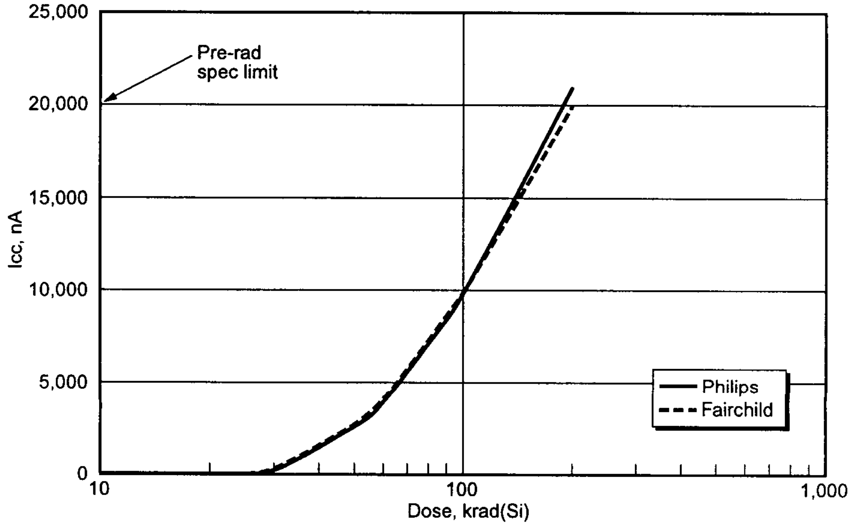

Figure 7. 74LVC138 Radiation Degradation

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