Comparison of Total Dose Effects on Micropower Op-Amps: Bipolar and CMOS*

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Abstract

Micropower op-amps; bipolar and CMOS, from Burr-Brown and Maxim are compared and critical parameters are characterized for total dose response with a 2.7V power supply voltage. The Burr-Brown bipolar device showed much more degradation than the CMOS device at high dose rate. The results are also compared with a NSC CMOS device. The Maxim bipolar device showed enhanced low dose rate effects.

I. INTRODUCTION

Single supply, low-voltage micropower op-amps are becoming increasingly popular in next-generation space system design applications. This paper compares four low-power op-amps: OPA241 (bipolar) and OPA336 (CMOS), from Burr-Brown; and MAX473 (bipolar) and MAX409 (CMOS), from Maxim, characterizing their total dose response with a single 2.7V power supply voltage. These op-amps are designed for low battery powered, small portable circuit applications, and can operate with a very wide range of power supply voltages.

Previous work [1] showed that a low-power National Semiconductor (NSC) CMOS op-amp, LMC6462, showed more parametric degradation with a 3V single supply voltage than with the conventional 5V power supply voltage at a dose rate of 100 rad(Si)/s. For the LMC6462, input offset voltage and input bias current showed more significant degradation with 3V supply voltage than 5V supply voltage. Its total dose failure level was comparable to that of bipolar op-amps. The present paper shows that some CMOS op-amps can withstand much higher radiation levels.

II. EXPERIMENTAL APPROACH

Four different op-amps were biased and characterized at 2.7V. Five devices of each type were irradiated with a cobalt-60 room type irradiator at room temperature at each dose rate. Burr-Brown devices were irradiated with a HDR of 50 rad(Si)/s. All devices were statically biased with a 2.7V voltage applied to inputs, using a closed loop unity gain circuit. An Analog Devices LTS-2020 test system was used for electrical characterization tests. After each irradiation level, the devices were taken out of the radiation room and electrical measurements were made with the LTS-2020 test system.

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III. TEST RESULTS

A. Burr-Brown Op-Amps

HDR Test Results

Input offset voltage is one of the most critical parameter of these micropower op-amps and the results are plotted in Figure 1. The bipolar op-amp, OPA241, showed a large degradation in input offset voltage because the maximum allowed change of the offset voltage (Vos) is only 250 mV. The input offset voltage increased more than an order of magnitude at 15 krad(Si). This bipolar device then failed functionally at 20 krad(Si); the output stuck at low. The output voltage change and functional failure were similar to the previous CMOS device, LMC6462 op-amp output failure, which failed catastrophically at a slightly lower level, 15 krad(Si).

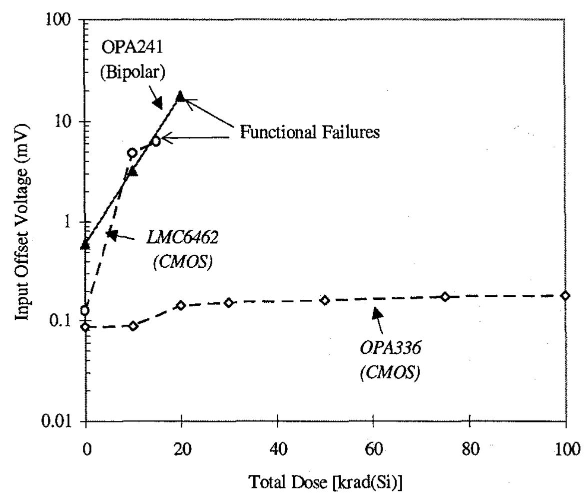

Figure 1. Comparison of the change in input offset voltage for two different technology op-amps at HDR 50 rad(Si)/s.

Input offset voltage of the other CMOS op-amp from NSC LMC6462 showed significant degradation. It exceeded the maximum specification limit of 3.7 mV at 8 krad(Si) and continuously increased up to the total dose level of 15 krad(Si) where the device became nonfunctional. The output voltage stuck at low so that the output high (Voh) could not be measured. The input offset voltage of the LMC6462 showed a recovery after high temperature 100°C annealing [1]. The amount of degradation in the input offset voltage is very different than the other Burr-Brown CMOS op-amp, OPA336.

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In contrast, the CMOS device, OPA336, showed very small changes in Vos up to the final total dose level of 100 krad(Si). The maximum specification limit for this device is only 125 mV. This CMOS device showed insignificant degradation in input offset voltage up to 100 krad(Si) at 50 rad(Si)/s whereas the bipolar device from Burr-Brown showed a large increase in the offset voltage and failed at 20 krad(Si). This is an unusually high failure levels for a linear CMOS device.

After a 120 hour room temperature annealing period, the output of the bipolar devices was still stuck low and the op-amp was not functional. Parameters did not recover after 168 hour room temperature and high temperature 100°C annealing period.

The input bias current (Iib) of the bipolar op-amp, OPA241, increased sharply up to 10 krad(Si). Then, it increased less severely to 20 krad(Si) where the device failed functionally. The degradation is shown in a solid line in Figure 2. The maximum specification limit is 20 nA. This device exceeded this maximum limit at below 10 krad(Si), a low total dose level for a bipolar device.

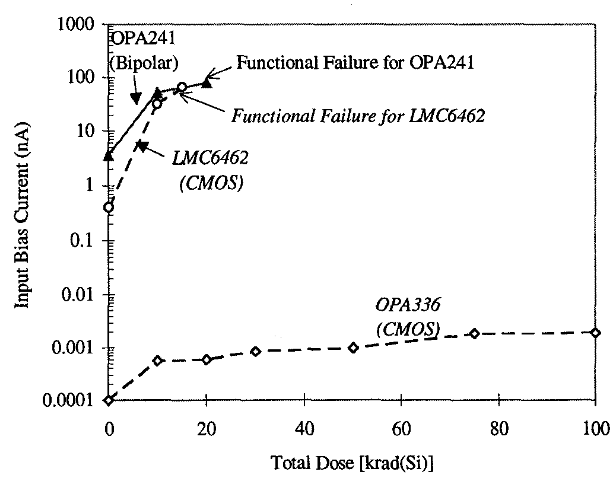

Figure 2. Input bias current degradation comparison of two different op-amp technologies with 50 rad(Si)/s.

The input bias current of the CMOS device (OPA336) showed insignificant degradation up to 100 krad(Si) where devices were still operational. The specification limit of Iib on this device is ±10 pA maximum but it remained below 10 pA even at 100 krad(Si). The input bias current of the other CMOS op-amp (LMC6462) degraded more than an order of magnitude above the specification limit of 0.2 nA max at about *5 krad(Si)*. This substantial increase in current is not a typical result of CMOS devices in low-voltage applications. The input bias current of the LMC6462 recovered during room-temperature annealing.

The supply current is specified 28 mA maximum for the OPA241 and 32 mA maximum for the OPA336. The bipolar device, OPA241 op-amp, showed much more severe degradation than the CMOS device, OPA336, as shown in Figure 3. The supply current exceeded the specification limits at about 2 krad(Si) for bipolar device and 15 krad(Si) for the CMOS device. The NSC CMOS op-amp, LMC6462, however, showed much more increase in the supply current up to the total dose level of 15 krad(Si). The supply current exceeded the specification limit of 75 mA at about 5 krad(Si).

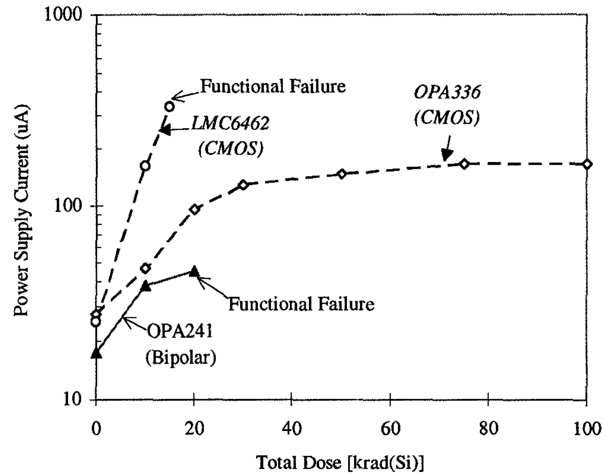

Figure 3. Change in supply currents for the Burr-Brown OPA241 and OPA336, and the NSC LMC6462 with 50 rad(Si)/s.

LDR Test Results

The CMOS op-amp, OPA336, showed slightly larger degradation with LDR at lower total dose levels, below 10 krad(Si) as shown in Figure 4. This is an interesting results because it is not a typical behavior of CMOS devices. Slightly less degradation was observed compared to the HDR results up to the final dose level of 30 krad(Si) and devices were functional at that level. The input offset voltage was within the maximum specification limit of 125 mV up to the HDR level of 15 krad(Si) and about 30 krad(Si) with LDR.

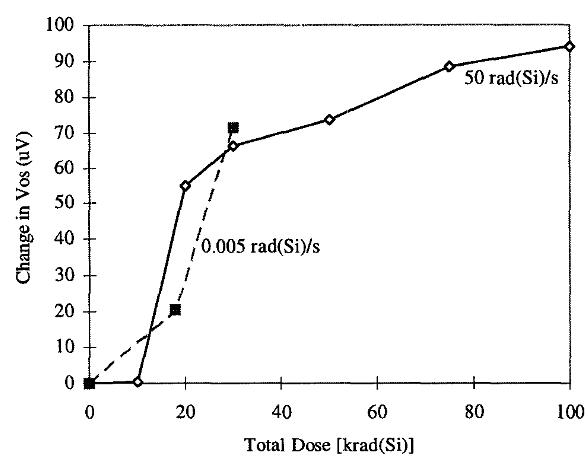

Figure 4. Comparison of input offset voltage degradation for the Burr-Brown OPA336 (CMOS) with two different dose rates.

The input bias current, however, showed larger degradation with HDR than LDR as shown in Figure 5. The input bias current degradation was very small and stayed within the maximum specification limit is 10 pA for both dose rates.

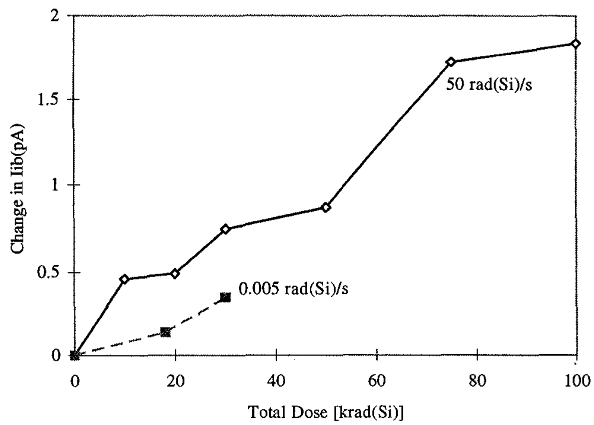

Figure 5. Comparison of input bias current degradation for the Burr-Brown OPA336 (CMOS) with two different dose rates.

Input offset voltage of the bipolar op-amp, OPA241, did not show any enhanced low dose rate (ELDR) effects below 20 krad(Si) as shown in Figure 6. The input offset voltage was with the maximum specification limit of 200 mV for both dose rates. However, devices failed functionally at 20 krad(Si) with HDR. At LDR, devices showed less degradation at lower total dose levels up to 20 krad(Si), but the input offset voltage increased sharply at 20-30 krad(Si). Devices remained functional up to the final dose level of 30 krad(Si).

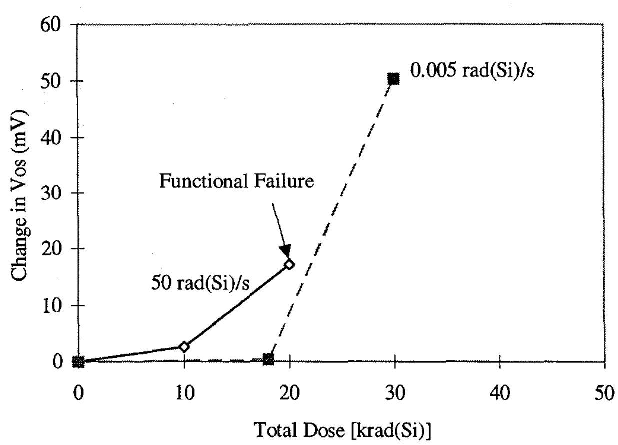

Figure 6. Comparison of input offset voltage degradation for the Burr-Brown OPA241 (bipolar) with two different dose rates.

The input bias current of the bipolar op-amp, OPA241, did not show any ELDR effects. It degraded much more severely with HDR than LDR as shown in Figure 7. There was a sharp increase in the input bias current at 10-20 krad(Si) with HDR. However, this parameter was within the maximum specification limit of 50 mA. The sudden increase in the input bias current at 20 krad(Si) could be major cause for the functional failure at HDR.

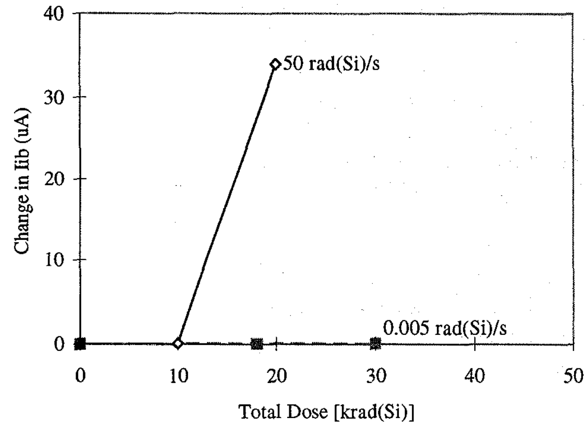

Figure 7. Comparison of input bias current degradation for the Burr-Brown OPA241 (bipolar) with two different dose rates.

B. Maxim Op-Amps

The input offset voltage of the CMOS op-amp, MAX409, showed slightly larger degradation at total dose levels below 10 krad(Si) with LDR. It is shown in Figure 8. Then it showed slight recovery at 18-30 krad(Si). At higher dose, after 12 krad(Si), there is a definitely larger degradation with HDR as expected in CMOS devices. The maximum specification limit is 0.25 mV. Therefore, devices exceeded the specification limit at much lower level with LDR, about 2 krad(Si) and 10 krad(Si) with HDR.

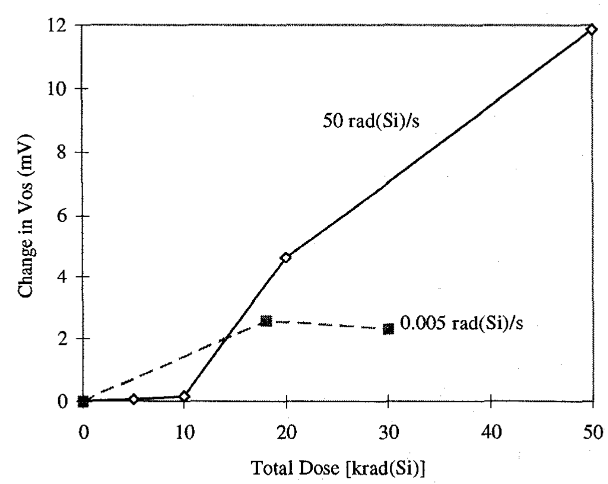

Figure 8. Comparison of input offset voltage degradation for the Maxim MAX409 (CMOS) with two different dose rates.

Similar characteristics were observed for the input bias current for MAX409. Iib showed slightly larger degradation at lower total dose levels, below 8 krad(Si) as shown in Figure 9. And slightly larger increase in degradation at higher dose levels. In other words, they showed relatively slight differences at both dose rates. However, due to the tight specification limit of 0.001 nA maximum, devices that were irradiated with LDR would exceed the specification at slightly earlier total dose level.

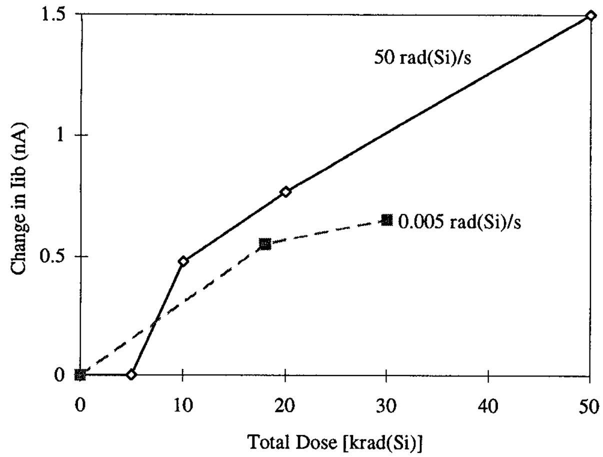

Figure 9. Comparison of input bias current degradation for the Maxim MAX409 (CMOS) with two different dose rates.

The bipolar op-amp, MAX473, however, exhibited ELDR effects. The input offset voltage degraded severely with LDR, almost 3 times greater than HDR results at 18 krad(Si) as shown in Figure 10. The maximum specification limit is 700 mA. It was exceeded at 12 krad(Si) with LDR and 36 krad(Si) with HDR. The ELDR degradation factor was about 3 times greater with LDR. The LDR degradation slope changed after 18 krad(Si) to 30 krad(Si), but it is still much larger than the HDR degradation.

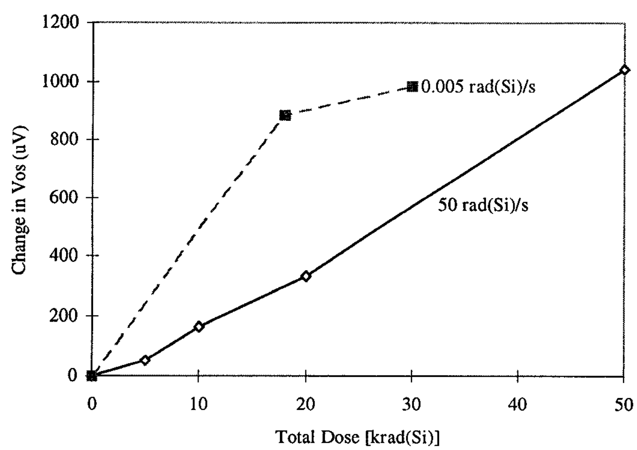

Figure 10. Comparison of input offset voltage degradation for the Maxim MAX473 (bipolar) with two different dose rates.

The input bias current degradation of the MAX473 is shown in Figure 11. The maximum specification limit of 80 nA was exceeded at 10 krad(Si) with LDR and 20 krad(Si) with HDR, factor by 2. The degradation was slightly greater at lower dose levels, below about 8 krad(Si) with HDR. However, at higher total dose levels, the degradation is much more severe with LDR.

IV. Discussion

The Burr-Brown bipolar op-amp showed much more severe degradation with HDR than the CMOS micropower op-amp with a low power supply voltage of 2.7V. This is a very different test

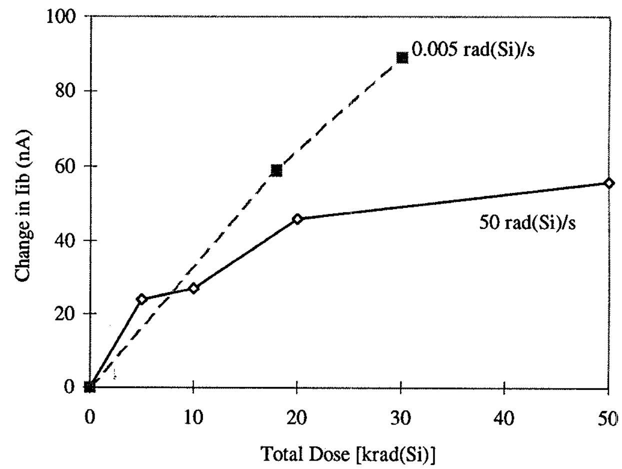

Figure 11. Comparison of input bias current degradation for the Maxim MAX473 (bipolar) with two different dose rates.

result than older reports which showed consistently the superior behavior of bipolar device technology than CMOS technology with HDR irradiation. Note that this bipolar op-amp is a higher voltage (36V) rated device, but it can be used in a low voltage applications as the manufacturer specified.

Table 1 lists the maximum operating rating voltages and functional failure levels for each devices. There appears to be an approximate correlation for the CMOS devices. The CMOS device with a very low maximum voltage operated satisfactorily at 100 krad(Si), about an order of magnitude higher than the level at which the other two CMOS devices stopped working all together. This may be related to difference in oxide thickness or field isolation.

The Burr-Brown CMOS device showed a promising result for low-power applications. Many bipolar devices show ELDR effects with LDR [2-7]. Therefore, LDR testing was performed to observe any ELDR effects on the bipolar op-amps from two

Table 1. Maximum Operating Rating Voltages for Devices

Device (Manuf.)	Technology	Voltage Rating	Functional Failure Level
OPA241 (Burr-B)	Bipolar	36V	20 krad(Si) (HDR)
OPA336 (Burr-B)	CMOS	5V	>100 krad(Si) (HDR)
LMC6462 (NSC)	CMOS	15V	15 krad(Si) (HDR)
MAX409 (Maxim)	CMOS	10V	10 krad(Si) (HDR)
MAX473 (Maxim)	Bipolar	6V	30 krad(Si) (LDR)

different manufacturers. The Burr-Brown op-amp did not show ELDR effects. However, the Maxim op-amp showed a classical ELDR effect and parameters degraded severely at LDR.

V. Conclusion

Two different bipolar op-amps from two different manufacturers behaved differently with LDR. The CMOS devices also showed slightly different degradation at both dose rates. The CMOS Burr-Brown device was functional up to greater than 100 krad(Si). The bipolar device, however, failed functionally at 20 krad(Si) HDR and it performed much better at LDR environment despite the high voltage rating and thick oxides. In contrast, the Maxim devices, MAX409 and MAX473, showed more conventional degradation with two dose rates.

The usage of micropower linear devices is increasingly important in space systems for low power and precision design applications. Internal matching requirements are more demanding for linear devices with low power supply voltages, but it appears possible to select devices - even CMOS, which is inherently more difficult to use in linear designs - with very high total dose failure levels. This is encouraging, but not all low-voltage CMOS devices are radiation tolerant. More work is needed to determine how processing and design affect the performance of CMOS devices in space.

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