Degradation of Precision Reference Devices in Space Environments

B. G. Rax, C. I. Lee, and A. H. Johnston
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

INTRODUCTION

Precision references are key components in many spacecraft applications, particularly those involving analog-to-digital conversion or similar precision-measurement functions. The voltage tolerance of these devices ranges from intermediate precision (≈ 0.01 %) to high precision (0.002%). Because of these very demanding requirements, voltage reference circuits can be affected by changes in internal device parameters that are considered to be second-order effects for more conventional circuits. For some devices, protons cause significantly more degradation than equivalent ionization levels with gamma irradiation.

This paper presents radiation test results for several different precision voltage devices. Their degradation is compared to that expected for the basic bandgap reference circuit, shown in Figure 1. This basic circuit, which is used as a theoretical benchmark, uses only npn transistors. Total dose degradation of this circuit was calculated using total dose and neutron displacement data from operational amplifiers with npn input transistors [1-3]. The results of this analysis are shown in Figure 2, assuming the environment is entirely due to protons. Note that even though this simple circuit does not use lateral or substrate pnp transistors, displacement damage still contributes a significant fraction of the net damage in this basic circuit in a proton environment.

Several different references were included in this work, including three high-precision devices with long-term stability below 0.003%, and one radiation-hardened device. All are fabricated with bipolar technology. Their characteristics are summarized in Table 1. The most critical parameter for these parts is usually long-term stability, not initial accuracy. Although most applications can tolerate some degradation in stability, it becomes increasingly difficult to use them when the voltage shift due to radiation exceeds 0.1 %. Even smaller voltage shifts can be tolerated for the high-precision devices.

Table 1. Devices Included in the Voltage Reference Study

Device	Manuf.	Voltage (V)	Accuracy (%)	Stability (%)	Special Features
LTZ1000*	Lin. Tech,	7.2	1	0.0002	Contains internal heater for temp. stability
LT1019A	Lin. Tech.	10	0.05	0.002	
AD2710	Anal. Dev.	10	0.01	0.0025	
REF02	Anal. Dev.	2.5	0.3	0.01	
REF02	Lin. Tech.	2.5	0.3	0.01	
AD674A	Anal. Dev.	10	1	0.01	Internal reference in 14-bit ND converter
RH1021	Lin. Tech.	5	1	0.03	Guaranteed performance to 100 krad(Si)

*The LTZ1000 is not a stand-alone device, but requires two external op-amps. RH 1056 op-amps were used to fabricate a working circuit with this device. Radiation tests were done in two ways: irradiation of the complete circuits, and irradiation of only the LTZ1000 device.

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RESULTS AND DISCUSSION

Because calculations show that the basic bandgap reference is significantly affected by displacement damage, proton tests were one of the key elements of the study. Proton damage experiments were done using 200 MeV protons at the University of Indiana. They were removed at selected intervals, measured with a high-precision voltmeter, and then subjected to additional irradiation. Ionization damage was determined by irradiating a different set of devices from the same date codes used for proton testing in a cobalt-60 facility using a dose rate of 50 rad(Si)/s. The test procedure was essentially the same as that used at the proton facility.

Results with Protons

Figure 3 compares the change in reference voltage for the device types with intermediate precision when they were irradiated with protons. Some device types exhibited positive changes after irradiation, while others were negative (dashed lines are used for those that exhibited negative changes). However, the changes for different units of a specific device type and manufacturer were always in the same direction. Note that although the REF-02 devices from two different vendors exhibited changes of nearly the same magnitude, they had opposite signs. The calculated degradation of the bandgap reference benchmark circuit is about O. 12% at a fluence of 4 x 10’1 p/cm^2. The degradation of three of the intermediate-precision devices is very close to that calculated for the simple bandgap circuit. Note further that even though these devices are far more complex than the basic bandgap reference, and contain pnp as well as npn transistors, for all but the AD674 the degradation is nearly linear with increasing levels of radiation.

The effects of proton irradiation on the three high-precision devices is shown in Figure 4. Although the degradation of all three device types was nearly linear, there were marked differences in the magnitude of the degradation. One of the high-precision devices, the LT 1019, degraded rapidly at low radiation levels to the point where its performance was more nearly that of the group of moderate-precision devices. The AD27 10 exhibited much less degradation.

The LTZ1 000, with the internal heater, performed far better than that of the other two precision devices. However, unlike the other devices, the LTZ 1000 is not a stand-alone part, but requires two operational amplifiers and other external components. It also is a very simple circuit with no internal pnp transistors. Figure 5 compares the degradation of this part when it was irradiated separately with results when the entire circuit (using radiation-hardened RH 1056 operational amplifiers) was irradiated with protons. The abrupt step at 1 x 10’2 p/cm^2 when the entire circuit was irradiated is caused by degradation of the input offset voltage of the RH 1056; this was verified by separate tests of the RH 1056 in the same proton environment (note that the RH 1056 is not hardened for displacement damage).

Ionization Damage

Ionization damage of the intermediate-precision references was reasonably consistent with the calculations using the basic bandgap reference circuit. Many devices exhibited more damage when they were irradiated with protons compared to cobalt-60 irradiation that produced equivalent ionization damage, and in some cases the differences between proton and cobalt-60 results was quite large, possibly because they use lateral and substrate pnp transistors with much wider base width than the npn transistors used in the simple bandgap reference. An example of these results is shown in Figure 6 for the AD27 10, a high-precision device. Table 2 below compares the change in the reference voltage for several of the devices at high dose rate. Because these devices are fabricated with bipolar technologies, they may exhibit substantially more damage at low dose rates [3-7]. The final paper will include results at low dose rate [0.002 to 0.005 rad(Si)/s] for comparison, using gamma irradiation.

Table 2. Relative Damage from Protons and Gamma Rays for Several Device Types

		% Change in V_{REF} at 20 krad(Si)			
Device	Manuf.	CO-60	Protons	Ratio	Comments
LTZ 1000	Lin. Tech.	0.005	0.0065	1.3	"Super zener" with int. heater
LT1019A	Lin. Tech.	-0.15	-0.165	1.1	
AD271O	Anal. Dev.	-0.0035	-0.028	8.0	
REF02	Anal. Dev.	0.12	0.13	1.1	
REF02	Lin. Tech.	-0.06	-0.0-1	1.1	
AD674A	Anal. Dev.	0.026	0.042	1.6	
RHI021	Lin. Tech.	0.065	0.17	2.6	Hardened for ionization damage
Band-Gap Ref.	- - -	0.085	0.155	1.8	*Theoretical circuit using only npn transistors*

The results of this paper show that significant degradation occurs at relatively low radiation levels in precision reference devices. For devices with intermediate precision, the nearly linear behavior and magnitude of the change in voltage from radiation is about the same as that expected in a simple bandgap reference circuit for both ionization and displacement damage. This implies that their internal designs are not too dissimilar from the basic bandgap reference,[+] and that similar assumptions about internal component matching are involved in the more elaborate designs used in practical circuits.

Two of the high-precision devices were much less affected by radiation. This is expected because such designs must incorporate additional corrections and compensation for internal component drift in order to meet the far more stringent temperature and stability requirements. However, the third device type was severely degraded at low radiation levels. The full paper will include data on the effect of radiation on temperature sensitivity, along with a more complete discussion of the circuit design and fabrication technologies used for the different types of circuits,

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[+] The full paper will include details of the analysis of the basic bandgap reference circuit, along with the assumptions used in calculating the degradation for both displacement and ionization effects.

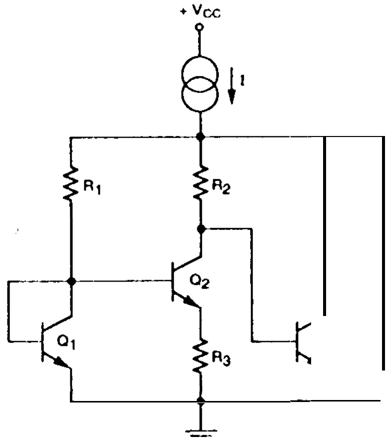

Figure 1. Basic Bandgap Reference Circuit Used for Benchmark Comparisons

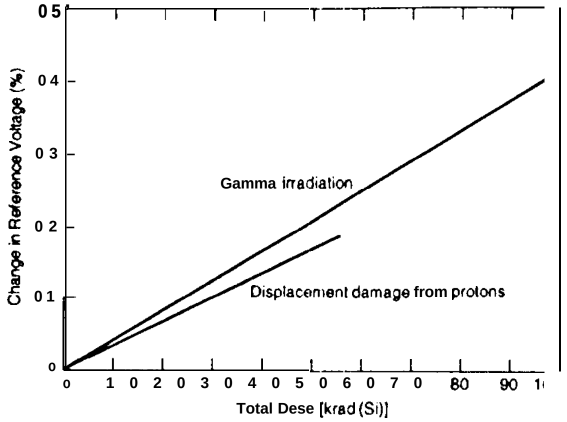

Figure 2. Calculated Degradation of Basic Bandgap Reference Circuit

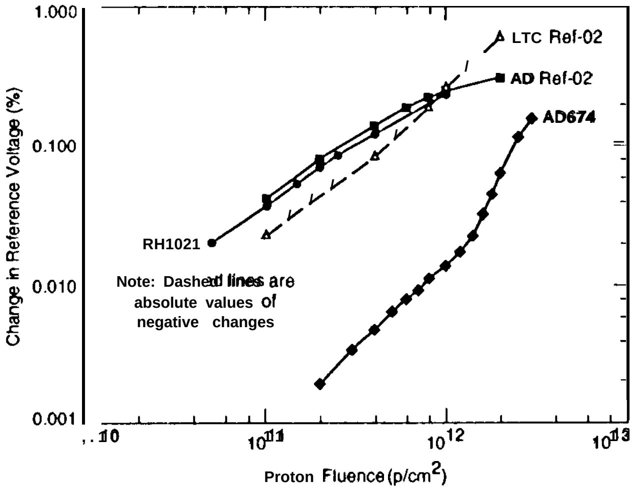

Figure 3. Proton Degradation of Moderate-Precision Reference Devices

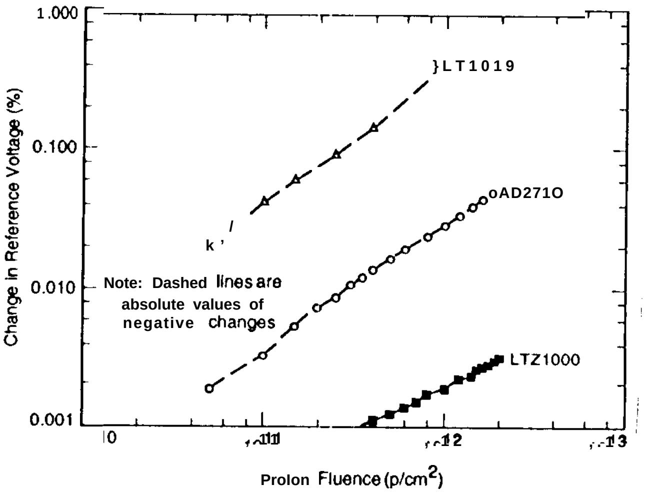

Figure 4. Proton Degradation of High-Precision Reference Devices

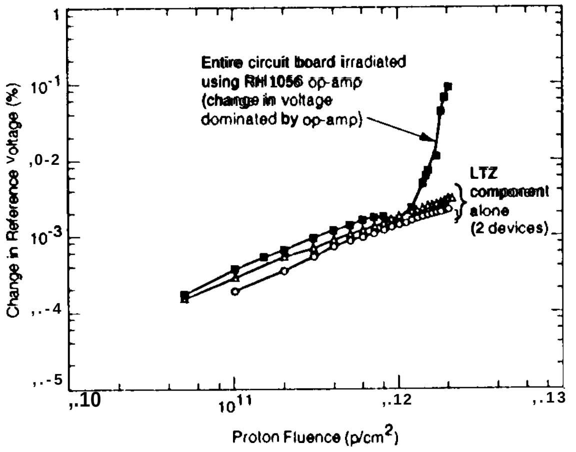

Figure 5. Degradation of LTZ1000 "Super-Zener" Device

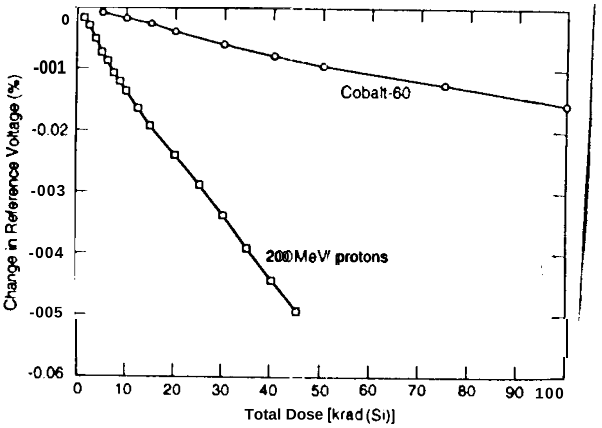

Figure 6. Comparison of Degradation of AD2710 in Proton and Cobalt-60 Environments