COMBINED RADIATION ENVIROMENT DAMAGE IN ELECTRONIC DEVICES

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When electronic devices are exposed to a combined environment of neutrons and gamma-rays, the devices' damage is often assumed to be the sum of the independent damage produced by neutrons and photons separately. Due to synergistic effects, it is possible that combined environment damage can be higher than the summation of the two damages individually. The radiation effects team at the University of Texas at Austin in partnership with Sandia National Laboratories, is measuring this synergistic effect in LM741 OpAmps using a MultiRad 350 irradiator for photons and the UT-NETL nuclear reactor for neutrons. Irradiations of devices are performed by neutrons separately, photons separately, neutrons followed by photons, and photons followed by neutrons in well characterized radiation fields. Outputs of the op-amps are collected during the irradiation to characterize the degradation with respect to dose and fluence applied. A synergistic radiation damage effect may be observed through these measurement methods.

Introduction

The current practice of evaluating radiation damage in electronics is that the expected damage mode due to irradiation of a device in a combined environment (e.g., one that includes both gamma-rays and neutrons) can be additively separable into its stress contributors. Thus, the damage mode from a Total Ionizing Dose (TID) stress component (e.g., from gamma-rays or energetic electrons) and displacement damage (e.g., from neutrons or energetic ions) can be evaluated separately and then additively combined to compute the expected total damage mode. There is interest in determining if there are synergistic effects that can occur in combined environment where a "synergistic" effect occurs when a "combined effect" results in behavior that differs from that predicted by the normal scaling of the individually applied stresses by a statistically meaningful amount [1]. Previous work by Yan et al. [2] present data suggesting that a synergistic effect is possible for the OP07 bipolar operational amplifier in a combined neutron and gamma irradiation environment.

In this work, researchers at the University of Texas at Austin (UT-Austin) developed a test methodology using the 1.1 MW TRIGA Mark II nuclear reactor at the Nuclear Engineering Teaching Laboratory (NETL) to study the possibility of synergistic effects on electronics in (1) a combined radiation environment where, for example, a gamma-ray stress and neutron stress are applied simultaneously to a device or (2) an ordered radiation environment where, for example, a gamma-ray stress is applied to a device and then in a short time period following that stress a neutron stress is applied to the device. The ordering of interest in this work involves applying a gamma-ray stress followed by a neutron stress or a neutron stress followed by a gamma-ray stress. The time period between the application of these stresses is short enough that the device has not fully recovered from the previously applied stress.

Ultimately, this research aims to characterize the damage caused by the Total Ionization Damage (TID) and displacement damage in a combined environment and when a device is subjected to stresses ordered in time and to compare the results to the additive combination of the effect of these stresses when evaluated separately. In this work, we provide preliminary results from studies with LM741 opamps, but the methodology developed here should be applicable to a variety of devices. A better understanding of damage to various electronic devices in a combined environment will help to improve the survivability of these components, especially for space-based components that may be subjected to radiation from solar events where the stresses will be ordered and separable in time.

Experimental Facilities

The experiments for this work involve four basic components:

1. **Testing Boards**. We developed printed circuit boards for mounting LM741 opamp devices and measuring device performance during irradiation. The electronics for the boards were designed to measure the inverted and non-inverted input bias current and slew rate before, during, and after irradiation. The testing board included positions for mounting dosimetry directly on the board in fixed and repeatable locations. The circuit board setup and associated electronics is shown in Figure 1.
2. **Dosimetry**. For recording the total ionizing dose and total 1-MeV (Si) equivalent neutron fluence provided to the test object, TLD-400 (CaF_2:Mn) thermoluminescent dosimeters and nickel foils were included on each board (for both TID and reactor irradiations). This included up to ten (10) TLDs and five (5) nickel foils per irradiation. For the gamma-only irradiation, nickel foils were excluded. TLDs were evaluated by staff at SNL's Radiation Metrology Laboratory (RML) in Albuquerque, New Mexico. Ni foils were counted at NETL using a calibrated HPGe. For measurement of dose during irradiation at the MultiRad, an ion chamber is included on the device to measure dose as a function of irradiation time. For reactor irradiations, an in-core fission chamber located near the irradiation location was used to measure neutron flux provided to the sample as a function fo time during irradiation.
3. **TID Irradiator**. Gamma-only irradiations were conducted using a MultiRad 350 irradiator present at the UT Austin's Dell Medical School. This allowed for irradiation of samples at an 18 Gy/min dose rate.
4. **Neutron Irradiator**. Neutron irradiations were conducted in the BP1-5 location at the UT-NETL 1.1 MW TRIGA Mark II nuclear research reactor. BP 1-5 is the central location of the Beam Port 1 and Beam Port 5 through tube which passes through the reactor reflector. This location places samples directly adjacent to the reactor core. Samples are inserted through the Beam Port 1 opening on an aluminum track that allows them to be placed repeatedly in the central location. BP1-5 is a dry irradiation beam port allowing for active measurement of devices during irradiation. Signal and power cables were run to the sample, passing through two polyethylene plugs that minimized the radiation dose at the exit of the beam port while still allowing cable connections during irradiation. The irradiation location included a 1" thick cylindrical lead filter around the samples to decrease gamma-ray dose from the reactor during operation. The irradiation location had been previously characterized to determine the neutron flux spectrum through irradiation of 29 flux foils and spectrum unfolding with both STAYSL and LSL-MOD.

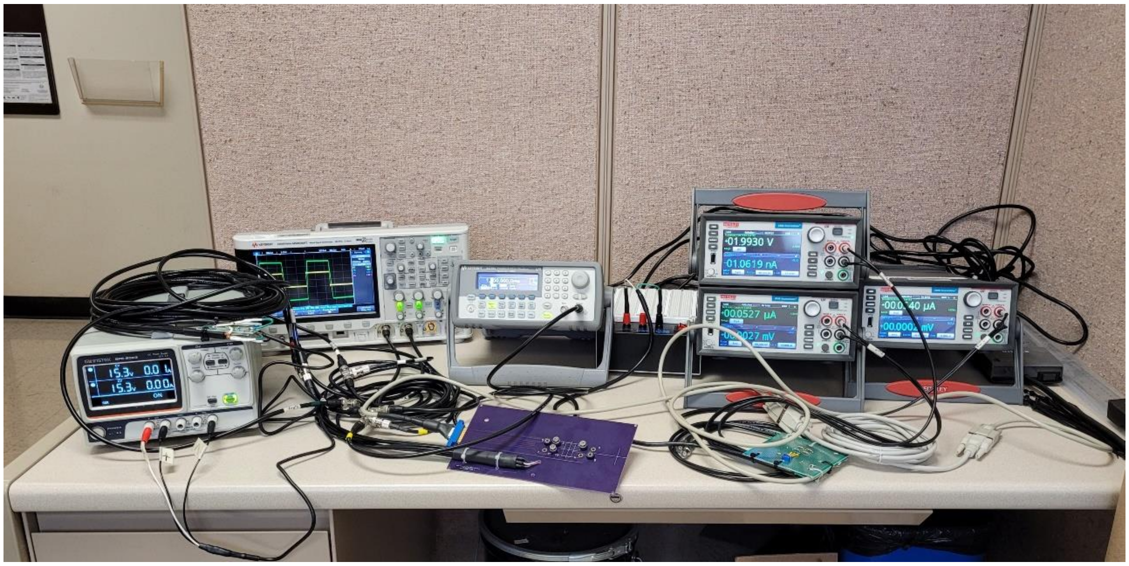

Figure 1: Printed circuit board and associated electronics used for opamp irradiations.

It is important to note that the TID Irradiator (MultiRad) and Neutron Irradiator (NETL) are not located in the same building. This necessitated the movement of samples between facilities which limited how short the time between successive irradiations could be. Samples irradiated using the MultiRad required at least 30 minutes of transportation time to arrive at the NETL. However, even more limiting was the movement of the neutron irradiated samples. These samples were activated following neutron irradiation and were required to decay for at least 6 days prior to transportation outside the reactor facility. Thus, these experiments were conducted with 7 days between successive NETL then MultiRad as well as MultiRad then NETL irradiations. Thus the successive irradiations were consistent, but there was significant lag time (longer than would be expected in a space environment).

Measurement Procedure

Experiments were performed irradiating opamps in photon-only and reactor-only environments. Preliminary measurements were also been performed in sequential environments. Opamp performance was measured during irradiation. The opamp input bias current and slew rate was measured relative to the measurement of the same parameter prior to the start of irradiation. It should be noted that these active measurements include current supplied to the device during irradiation and some current annealing is expected. Multiple opamps were irradiated in each condition. Dosimetry was recorded both during irradiation and using TLD’s and Ni foils to get a more accurate total dose and neutron fluence.

Results

The opamp performance was measured by evaluating its slew rate and input bias current in one minute intervals. The slew rate was taken from the negative slope of the opamp’s output square wave. This value is the average of all the negative slopes in the square wave at a specific dosage. The slew rate is then normalized with the initial slew rate of the virgin opamp. Input bias current is evaluated by measuring the change in the current.

Across multiple photon-only irradiations, the slew rate degradation showed similar results. As seen in Figure 2, regardless of final irradiation the opamps all show similar slew rate degradation with respect to the dose. The slew rate ratio reached zero at ~600 Gy (Si), showing that the opamp had completely failed. If the opamp did not fail, it had the opportunity to recover after photon-only irradiation. This recovery was not seen in samples irradiated with neutrons.

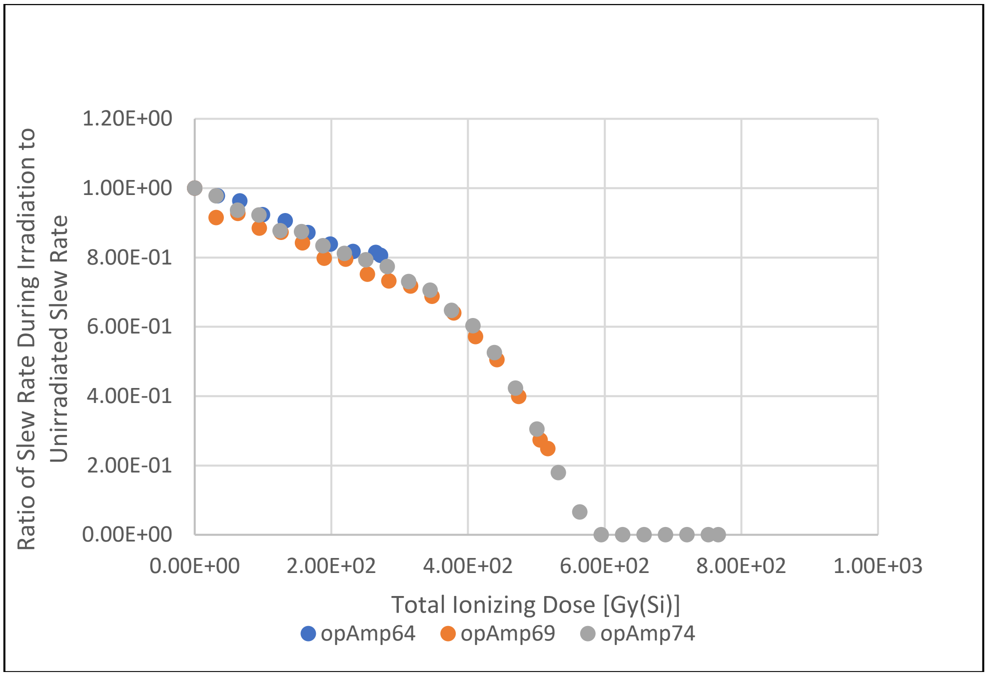

Figure 2: Change in Slew Ratio Versus Total Ionization Dose for Photon Only Measurements for Three Different OpAmps

Input bias current was shown to grow with respect to radiation dosage. Figure 3 shows the increase in input bias current with respect to neutron fluence for the reactor irradiations. Figure 4 similarly shows the increase in input bias current for the photon-only experiments.

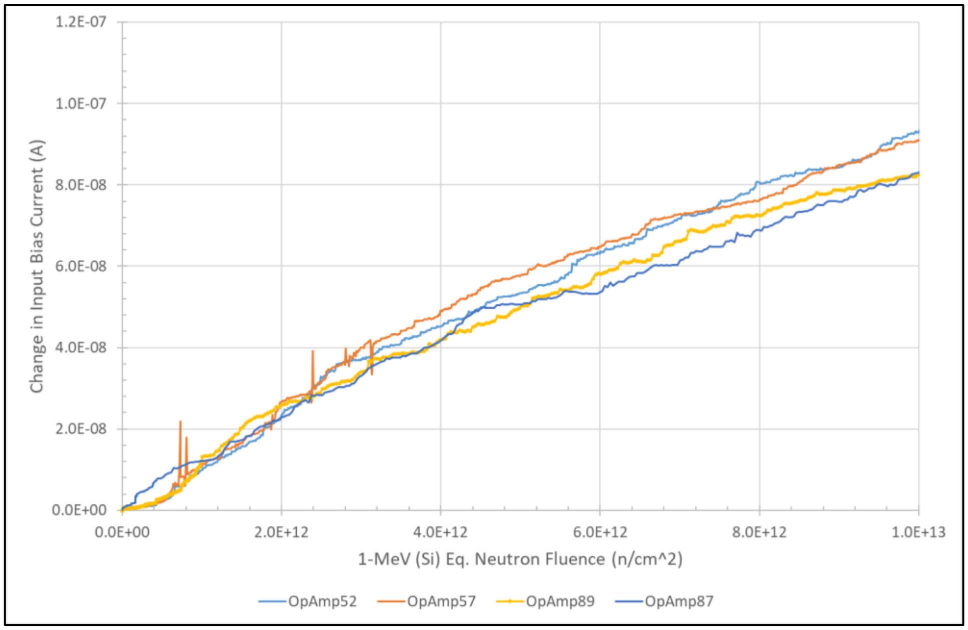

Figure 3: Change in Inverted Input Bias Current Versus Neutron Fluence for Neutron Only Measurements

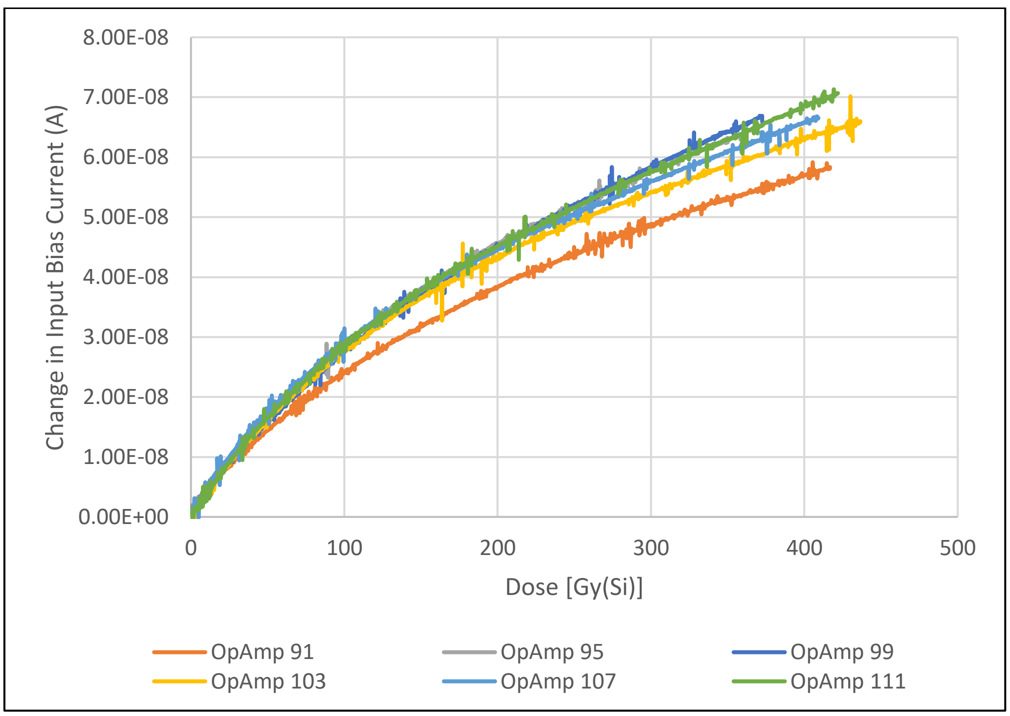

Figure 4: Change in Input Bias Current Versus Dose for Photon Only Measurements

Future work will irradiate the circuit boards with both photons and neutrons. Like the induvial irradiations the photons will be produced via the MultiRad 500 and the neutrons by the NETL reactor. For the photon then neutron irradiation the circuit board will be first irradiated in the MultiRad 500 and followed by the reactor. The reverse would occur for a neutron then photon irradiation. The will be a time delay between these two irradiations due to the instruments being at different facilities.

The slew rate and input bias current will be captured actively during the irradiations and on passive op amps after the irradiation like on the single irradiation experiments. This data will then be analyzed and compared to each other as well as the single radiation experiments.

Conclusion

Current data shows a substantially higher slew rate degradation done by displacement irradiation in the reactor than with ionizing radiation in the MultiRad 350. Future experiments at NETL will test combined neutron and photon effects on the circuit boards. This will be done by moving the circuits boards between the MultiRad 350 and the NETL reactor and vice versa. The results will then be analyzed and compared to the damage caused by single source radiation environments.
So far, the team has yet to eliminate all the gamma rays in the reactor only irradiation. Due to this there is no neutron only environment, only a neutron with light gamma ray environment. Due to the current test set up at UT Austin there is a delay between MultiRad 350 and reactor irradiations. This allows for time for the opamps to anneal between the irradiations. The analysis of the irradiations also only accounts for slew rate performance with respect to dose and does not account for the dose rate applied to the device.

The team plans to continue its test both with individual gamma ray and reactor irradiations as well as combined irradiations. It will continue with these tests and use the analysis to compare with the results from IBL and ACRR data from Sandia National Laboratory in Albuquerque, New Mexico.

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