Measurements of Proton Displacement Damage in Several Commercial Optocouplers

Farokh Irom, Gregory R. Allen, *Member IEEE*, and Bernard G. Rax

***Abstract*-- Proton Displacement Damage (DD) measurements on Isolink OLS049, Micropac 66296-101, 66224-103JANTX, and 66179-003 are reported. The 66179-003 has the worst degradation, 13% of the initial CTR remains when it is used with I_F = 10 mA at 1 x 10^{12} 1-MeV n/cm^2 fluence in Silicon. The remaining CTR percentage for OLS049, 66296-101, and 66224-103JANTX are 21%, 32%, and 79% at 2 x 10^{12} 1-MeV n/cm^2 fluence in Silicon, respectively.**

I. INTRODUCTION

Optocouplers are widely used in electronic systems to provide electrical isolation between different circuits. A diagram of a basic optocoupler is shown in Fig. 1. The normal parameter of interest is the current transfer ratio (CTR) defined as the ratio of the collector current of the transistor to the forward current through the light-emitting diode (LED) [2].

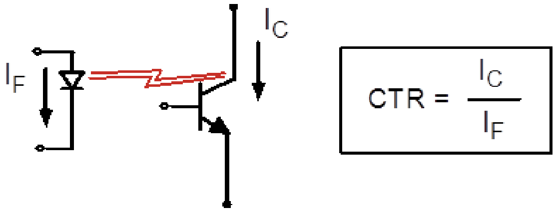

Fig. 1. Diagram of a basic optocoupler using a phototransistor [2].

Radiation degradation in optocouplers is an important issue for space applications [1]–[9]. There are three radiation issues affecting optocouplers for space flight applications: displacement damage (DD), total ionizing dose (TID) and single event transient (SET) [8]. TID and DD can both cause degradation in optocouplers and effect CTR. SETs can be induced by protons and heavy ions.

In general, the LED of an optocoupler is effected by DD the coupling medium is degraded by TID and the photodetector and amplification circuit are effected by TID and SET.

CTR Degradation of optocouplers with simple phototransistors due to radiation depends on several factors [2]:

1-Degradation of the internal LED.

2-Decrease in the effective gain of the phototransistor due to decreased light output (and consequently lower photocurrent) from the LED.

3-Degradation of gain and photoresponse of the phototransistor.

4-Degradation of the coupling medium between the LED and phototransistors.

In addition to these factors, temperature also plays a role in the degradation. Initially the CTR is higher for higher temperatures, but the positive temperature coefficient becomes negative after low levels of radiation exposure.

For optocouplers with amphoterically Si-doped Gallium Arsenide (GaAs) LEDs, the extreme sensitivity of the LED to radiation damage [1] causes the first mechanism to dominate the degradation, although there is some effect from the second mechanism as the LED light output decreases.

For optocouplers with other LED technologies, all four mechanisms can be important. This makes it far more difficult to evaluate radiation degradation for that type of optocoupler. Among the complications is far greater statistical variation in the radiation degradation of optocouplers, due to the dependence of optocoupler performance on several different factors [2].

Solar protons and trapped protons predominate the natural space environment and contribute to both TID and DD. Depending on an optocoupler primary degradation mode, proton irradiations can produce results that are either nearly identical to ^{60}Co TID tests or can show substantially more degradation than would be expected from TID alone [8]. Neutrons are important primarily for avionics and manmade nuclear environments and contribute almost exclusively to DD [8].

This paper reports radiation test results for the following commercial optocouplers shown in Table I. The Electrical parameters for these optocouplers are similar to the JEDEC

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registered 4N49U optocoupler, but with better CTR degradation characteristics due to radiation exposure.

TABLE I LIST OF THE PARTS

Manufacture	Part Number	Date Code
Isolink	OLS049	1318
Micropac	66296-101	1338
Micropac	66224-103JANTX	1449
Micropac	66179-003	1143

II. DEVICE INFORMATION

The Isolink OLS049 optocouplers incorporate an internal heterostructure doped Aluminum Gallium Arsenide (AlGaAs) LED and an N-P-N silicon photo-transistor that is electrically isolated, but optically coupled inside a hermetic, four-pin Leadless Chip Carrier (LCC) package. The OLS049 LED has an 800 nm wavelength.

The Micropac 66296 is a quad optocoupler, consisting of four 850 nm Gallium Aluminum Arsenide (GaAlAs) LEDs and four silicon phototransistors mounted and coupled in a miniature surface mount hermetic LCC package.

The Micorpac 66224 is a hermetically sealed single channel device. The device incorporates a high radiance LED and silicon phototransistor. The LED is a doped GaAlAs heterostructure with an 850 nm wavelength.

The Micropac 66179 is a single channel optocoupler, consisting of a single 660 nm GaAlAs LED and a single silicon phototransistors mounted and coupled in a miniature surface mount hermetic LCC package.

III. EXPERIMENTAL PROCEDURE

Ref [8] compares degradation ^{60}Co irradiation of a 4N49U type optocoupler to that for 195 MeV proton irradiation. Proton irradiations cause significantly larger degradation than gamma ray exposures at equivalent doses. This type of optocoupler response is due to the greater amount of displacement damage for protons over gamma exposures [9].

All the devices studied in this paper are 4N49U type and the dominant mechanism for degradation is displacement damage from solar protons and protons trapped in a planet’s radiation belts. Although there is a full spectrum of proton energies in the actual space environment, it is costly and impractical to test devices over the full spectrum of proton energies. The preferred approach is to do tests with protons at a single energy, relying on published studies of the energy dependence of proton damage to relate the measured results at a single energy to the effect of the broad spectrum of energies in the actual space environment [5].

We use the concept of non-ionizing energy loss (NIEL) to define an equivalent 1-MeV neutron fluence to interpret displacement damage. In other words, radiation environments of protons, neutrons and electrons are regarded as equivalent if they produce the same nonionizing dose when proper NIEL factors for protons, neutrons and electrons are used to calculate the dose. Although, the devices being studied in this report are not silicon based, we nonetheless choose to report fluences in 1 MeV neutron equivalent in silicon as this is a standard way that many missions report their environment. DD measurements were performed with proton beams at the $1\text{x}10^{11}$, $5\text{x}10^{11}$, $1\text{x}10^{12}$, $2\text{x}10^{12}$ and $5\text{x}10^{12}$ equivalent 1-MeV neutron fluences in silicon. These standard fluences were converted to the equivalent proton fluences using the NIEL factor appropriate to the beam energy and device material.

The first 2 devices in Table I were tested at the Canada's National Laboratory for Particle and Nuclear Physics (TRIUMF) using 105-MeV protons. The third device in Table I was tested at TRIUMF using 63-MeV protons. The last device in Table I was tested at University of California Davis (UCD) using 67-MeV protons. Five devices of each of the optocouplers were irradiated. The devices were exposed at room temperature to a series of radiation steps with electrical and optical measurements made before irradiation and between each step. All parts were in an unbiased condition during irradiation (all pins grounded) to make the test conditions unambiguous. DD effects are, to first order, insensitive to bias conditions during irradiation.

After each irradiation level, the optocoupler CTRs were measured over a range of forward current (I_F) values using the HP 4156 Semiconductor Parameter Analyzer. The current was varied from 1 to 10 mA as shown in Table II.

Table II. Measurement Parameters for the Optocouplers

MEASUREMENT	CONDITIONS
CURRENT TRANSFER RATIO	I_F = 1, 2, 4, 6, 8 AND 10 MA

Temperature has a noticeable effect on optoelectronic properties but there are competing effects [4-6]. For some optocouplers, the CTR without irradiation increases with increasing temperature, but this dependency reverses after radiation exposure. The power output of typical LEDs decreases approximately 1% per degree Celsius [6]. All devices were placed in a temperature controlled test chamber during measurements. Measurements were made at two temperatures, 25 ºC and 60 ºC, maintaining the temperature to a precision of ± 0.2 ºC.

IV. TEST RESULTS AND DISCUSSION

A. ISOLINK OLS049

Fig. 2 displays the average normalized CTR (the post-irradiated value divided by the pre-irradiated value) for five samples versus the neutron equivalence fluences for each tested value of I_F (1, 2, 4, 6, 8 and 10 mA). The CTR after accumulation of 2 x 10^{12} n/cm^2 is very small and it was decided to skip the last step of irradiation at 5 x 10^{12} n/cm^2.

LED degradation is given by [1]

$$\left[\left(\frac{L_o}{L}\right)^n - 1\right] = K\,\tau_o\,\Phi \qquad (1)$$

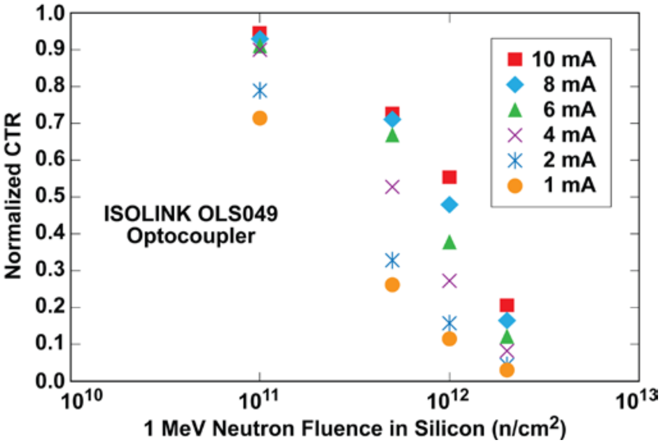

Fig. 2. Normalized CTR versus the radiation level for the OLS049.

where L_o is the pre-irradiation light intensity, L is the light intensity after irradiation, n is an exponent that is typically between 1/3 and 1, K is the damage factor, τ_o is the pre-irradiation minority carrier lifetime, and Φ is the particle fluence. With n determined from test data for a device of interest, the linear relationship between fluence and the quantity on the left side of (1) provides a way to interpolate results at intermediate radiation levels. However, (1) describes only LED degradation. The entire device requires more considerations as discussed in the next paragraph.

An accurate analysis recognizes that even if degradation caused by radiation was solely in the LED, the phototransistor gain would still have an implicit dependence on this degradation because the gain depends on the photogeneration rate which is affected by degradation of the LED [2]. An algorithm for including these effects to obtain accurate fits to data is given in [3] but the equations are cumbersome and the higher accuracy is not needed for the examples given here. A less accurate but simpler approximation is used here to derive an alternate plotting format. This approximation regards the phototransistor gain as a constant so that CTRs are in the same ratio as the light intensities in LEDs. The approximation then becomes:

$$\left[\left(\frac{CTR_o}{CTR}\right)^n - 1\right] \approx K\,\tau_o\,\Phi \qquad (2)$$

where CTR_o is the pre-irradiation optocoupler gain and CTR is the gain after irradiation. The alternate plotting format suggested by (2) plots the left side as a function of fluence. To the extent that (2) is valid, a suitably selected n will make the left side proportional to fluence (a straight line with unit slope in a log-log plot). A subset of the data in Fig. 2 (2 and 10 mA) are plotted in this format in Fig. 3 using a value of n that produces a best fit to a straight line with unit slope in a log-log plot. The best-fitting n for this data set is 1/3 which is typical for the heterostructure LED used in that device.

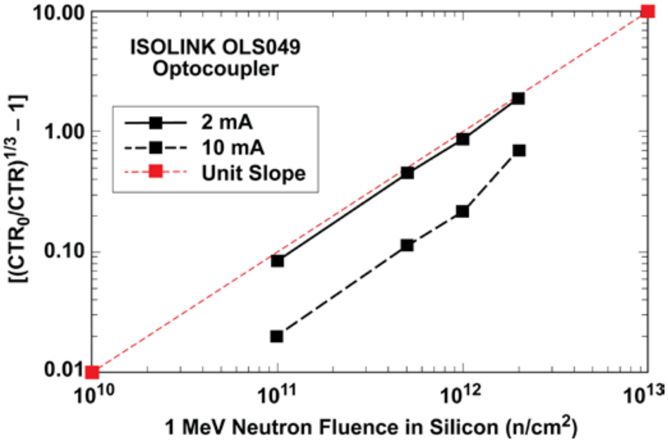

Fig. 3. Values of [(CTRo/CTR)$^{1/3}$ – 1] for $I_F = 2$ and 10 mA for OLS049.

B. *MICROPAC 66296*

Fig. 4 displays the average normalized CTR for five samples versus the neutron equivalence fluences for each tested value of I_F (1, 2, 4, 6, 8 and 10 mA).

The plotting format explained in the discussion of Fig. 3, and using n = 2/3 for the 66296, converts Fig. 4 into Fig. 5. Deviation of data for $I_F = 2$ and 10 mA from unit slope can be attributed to degradation of 66296 phototransistor.

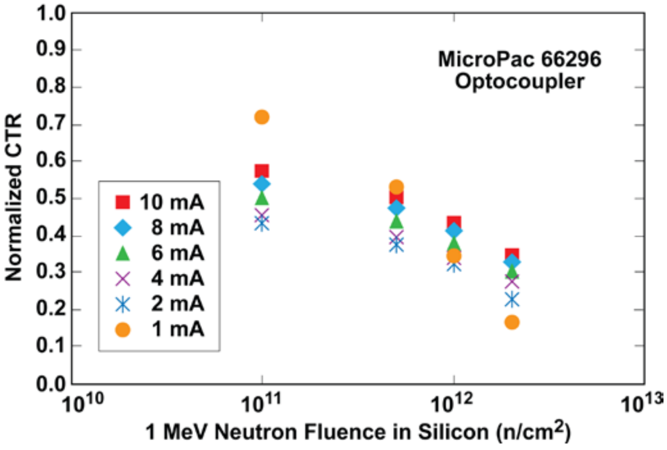

Fig. 4. Normalized CTR versus the radiation level for the 66296.

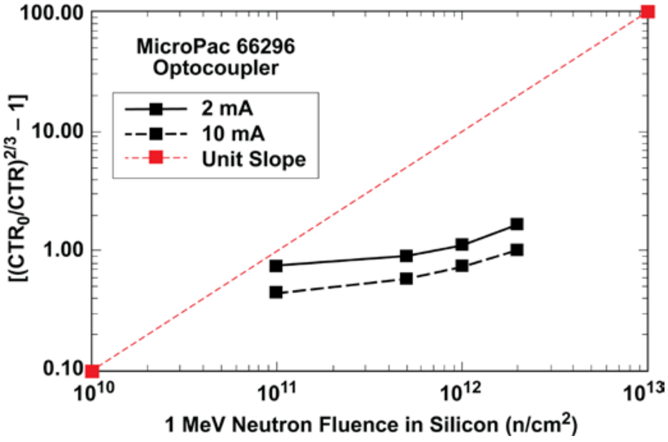

Fig. 5. Values of [(CTRo/CTR)$^{2/3}$ – 1] for $I_F = 2$ and 10 mA for 66296.

C. *MICROPAC 66224*

Fig. 6 displays the average (over five samples) normalized CTR versus the neutron equivalence fluence for each tested value of I_F (1, 2, 4, 6, 8 and 10 mA).

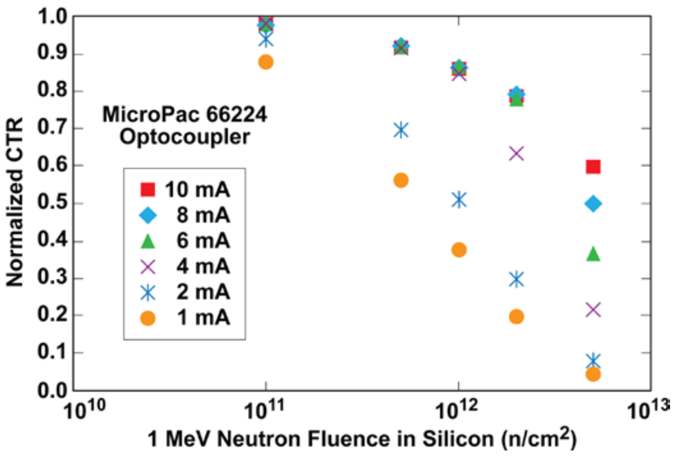

Fig. 6. Normalized CTR versus the radiation level for the 66224.

In Fig. 7, we compare the average normalized CTR at room temperature and elevated temperature of 60° C for the Micropac 66224. The CTR measurements show temperature dependence at fluence levels above 1 x 10^{12} 1 MeV n/cm^2.

The plotting format explained in the discussion of Fig. 3, converts Fig. 6 into Fig. 8. The best-fitting n for this data set is 2/3.

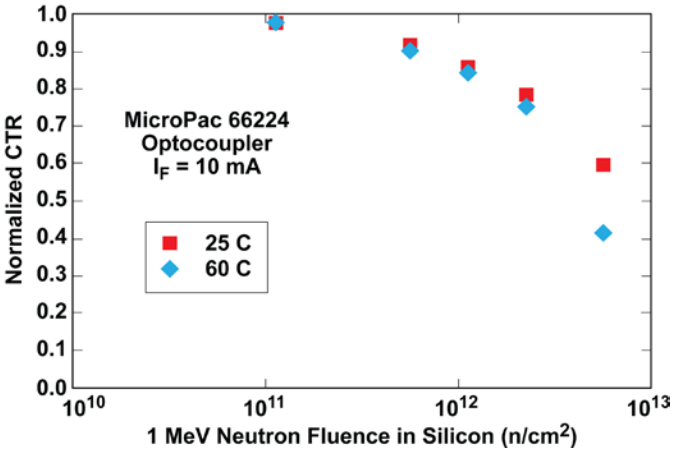

Fig. 7. Normalized CTR versus the radiation level for room temperature and 60^o C for 66224.

D. *MICROPAC 66179*

Fig. 9 displays the normalized CTR, averaged over four device samples, and versus the neutron equivalence fluences for each tested value of I_F (1, 2, 4, 6, 8 and 10 mA). The CTR after accumulation of 1 x 10^{12} n/cm^2 is very small and it was decided to skip the last steps of irradiation at 2 x 10^{12} and 5 x 10^{12} n/cm^2.

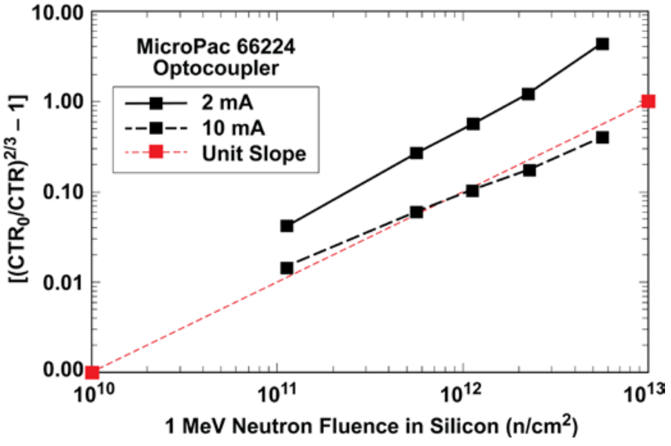

Fig. 8. Values of $[(CTRo/CTR)^{2/3} – 1]$ for $I_F = 2$ and 10 mA for 66224.

A subset of the data in Fig. 9 (2 and 10 mA) are plotted in the format explained in the discussion of Fig. 3 in Fig. 10 using a value of n that produces a best fit to a straight line with unit slope in a log-log plot. The best-fitting n for this data set is 2/3.

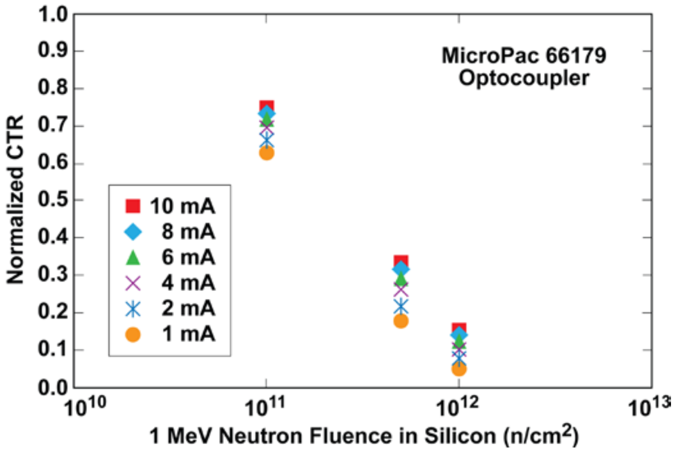

Fig. 9. Normalized CTR versus the radiation level for the Micropac 66179.

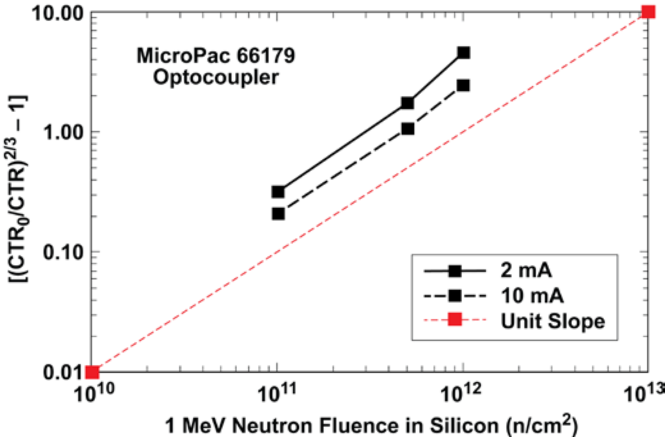

Fig. 10. Values of $[(CTRo/CTR)^{1/3} – 1]$ for $I_F = 2$ and 10 mA for 66179.

V. CONCLUSION

This paper summarizes the results of radiation tests for four different types of optocouplers.

In Fig. 11 we compare measured CTR values for I_F = 10 mA for Isolink OLS049, Micropac 66296, Micropac 66224, and Micropac 66179 together so that the different devices can be compared to each other. Also included in this comparison are data from Ref. 7 for Avago HCPL5700, Isocom CSM141A, Isocom CSM1800, Iscom IS49 and Isolink OLH249. The OLH249, IS49, OLS049, 66296, 66179 and 66224 are electrically identical to JEDEC registered 4N49 optocoupler. The Micropac 66224 clearly has much less degradation compared to the other devices. The 66224 CTR degradation at I_F = 10 mA and 2 x 10^{12} 1-MeV neutron fluence in silicon is only about 20% compare to 90% degradation for OLH249. The 66224 has a double heterostructure doped LED and OLH249 also has an internal heterostructure doped LED. It has been shown that doped heterostructure LEDs show far less radiation damage. Therefore, most likely the poor performance of OLH249 is due to degradation of the internal photo-transistor.

Additional derating is also required for reliability. Optocoupler reliability is less straightforward because other factors –such as the coupling compound used between the LED and phototransistor – also affect long-term performance. A minimum adjustment factor of 10% is recommended to account for aging [2], which has not already been accounted for in this study.

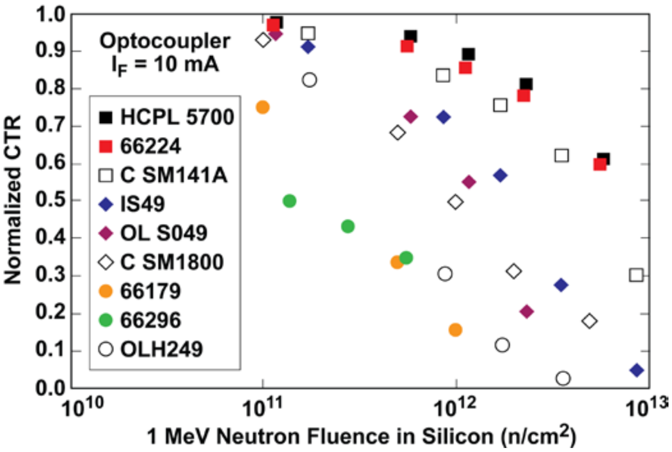

Fig11. Comparison of normalized CTR for Isolink OLS049, Micropac 66224, Micropac 66179 and Micropac 66296. Also shown are data for Avago HCPL5700, Isocom CSM141A, Isocom CSM1800, Isocom IS49 and Isolink OLH249.

VI. REFERENCES

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