Proton Displacement Damage Measurements in Commercial Optocouplers

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***Abstract*-- Proton Displacement Damage (DD) measurements on Isolink OLH249, Isocom IS49, Isocom CSM141A, Isocom CSM1800 and Avago HCPL-5700 are reported. The OLH249 has the worst degradation, 3% of the initial CTR remains when it is used with I_F = 10 mA at 3 x 10^{12} 1-MeV n/cm^2 fluence in Silicon. The remaining CTR percentage for IS49, CMS141A, CSM1800 and HCPL-5700 are 28%, 62%, 32%, and 81% at 3 x 10^{12} 1-MeV n/cm^2 fluence in Silicon, respectively.**

I. INTRODUCTION

DISPlacement damage (DD) in optocouplers is an important issue for space applications [1–6]. This type of damage from protons is the dominant mechanism for degradation of these devices.

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).

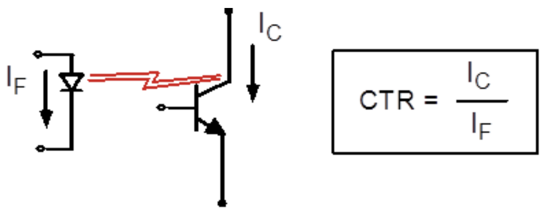

Fig. 1. Diagram of a basic optocoupler using a phototransistor [2].

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 are 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].

The studies discussed in this paper were undertaken to establish the sensitivity of optoelectronic devices to radiation damage from protons. Proton degradation is investigated for several different types of optocouplers.

TABLE I LIST OF THE PARTS

Manufacture	Part Number	Date Code
Isolink	OLH249	1232
Isocom	IS49	1429
Isocom	CSM141A	1429
Isocom	CSM1800	1429
Avago	HCPL-5700	1410

II. DEVICE INFORMATION

This paper reports radiation test result for the following optocouplers shown in Table I.

The Isolink OLH249 optocouplers incorporate an internal heterostructure doped GaAs LED and N-P-N silicon photo-transistor. Electrical parameters for OLH249 are similar to

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the JEDEC registered 4N49 optocoupler. The OLH249 LED has an 820 nm wavelength.

The Isocom ISL49 is a single channel device which consists of a infra-red double heterostructure doped GaAs LED and a silicon photo-transistor. Electrical parameters for IS49 are similar to the JEDEC registered 4N49 optocoupler. The ISL49 LED has an 850 nm wavelength.

The Isocom CSM141A optocouplers incorporate an internal double heterostructure doped (GaAs) LED and high gain silicon photon detector (photodarlington). Electrical parameters for CSM141A are similar to the JEDEC registered 6N140A optocoupler. The CSM141 LED has an 850 nm wavelength.

The Isocom CSM1800 is a single channel device. The device incorporates a high radiance LED and silicon phototransistor. The Isocom CSM1800 is a single hermetically sealed optocoupler and incorporates a high radiance heterostructure doped GaAs LED and silicon phototransistor. The CSM141 LED has an 830 nm wavelength.

The Avago HCPL-5700 is a quad channel device optocoupler. Each channel contains a Gallium Arsenide Phosphide (GaAsP) LED which is optically coupled to an integrated high gain photon detector (photodarlington). Electrical parameters for HCPL-5700 are similar to the JEDEC registered 6N141A optocoupler.

It is important to note that most optocouplers are relatively complex hybrids. For example, the HCPL-5700 in addition to being a four channel coupler, also contains a photodarlington detector circuit ("high gain photon detector").The photodarlington transistor uses the standard transistor Darlington configuration. Within this circuit configuration, the gain of the Darlington transistor pair is that gain of the two individual transistors multiplied together. In the photodarlington transistor configuration, the first transistor acts as the photodetector, and its emitter is coupled into the base of the second transistor. This gives a very much higher level of gain, but it is very much slower than the ordinary phototransistor. Thus, the nature of the detector portion of the coupler has strong implications for the expected coupler radiation response.

III. EXPERIMENTAL PROCEDURE

The dominant mechanism for degradation of optoelectronics is displacement damage from solar protons, or electrons 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 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.

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. DD measurements were performed with proton beam at the $1x10^{11}$, $5x10^{11}$, $1x10^{12}$, $2x10^{12}$ and $5x10^{12}$ equivalent 1-MeV neutron fluences in Silicon.

The first 3 devices in Table I were tested at the University of Indiana, Bloomington, cyclotron (IUCF) using 200-MeV protons. The last two devices in Table I were tested at University of California Davis (UCD) and Canada's National Laboratory for Particle and Nuclear Physics (TRIUMF) using 65-MeV and 105-MeV protons, respectively. Five devices of each of the optocouplers were provided for radiation testing. 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) because DD effects are, to first order, insensitive to bias conditions during irradiation.

After each irradiation level, the optocoupler CTRs were measured for a set of values of the forward current (I_F) through the LED 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 initially the CTR is higher for higher temperatures, but the positive temperature coefficient becomes negative after low levels of radiation exposure. After radiation exposure, the power output of typical LEDs has a negative temperature coefficient, decreasing 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 OLH249

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 IF (1, 2, 4, 6, 8 and 10 mA). The CTR after accumulation of 3 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.

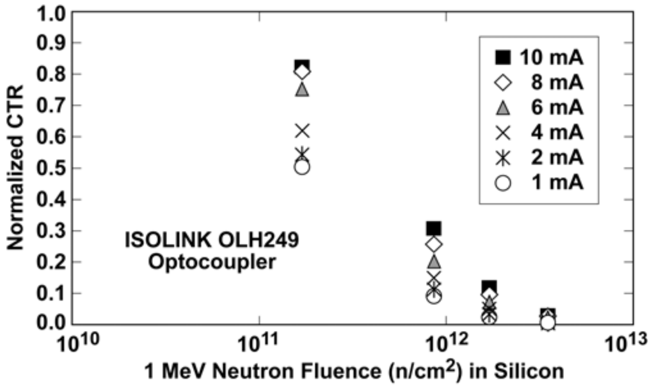

Fig. 2. Normalized CTR versus the radiation level for the OLH 249.

LED degradation has a super linear dependence on displacement damage. A linear relationship can be established using the following equation [1]:

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

where Lo 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 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 Eq. (1) provides a way to interpolate results at intermediate radiation levels.

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. 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, *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 (1) 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 appropriate for the heterostructure LED used in that device.

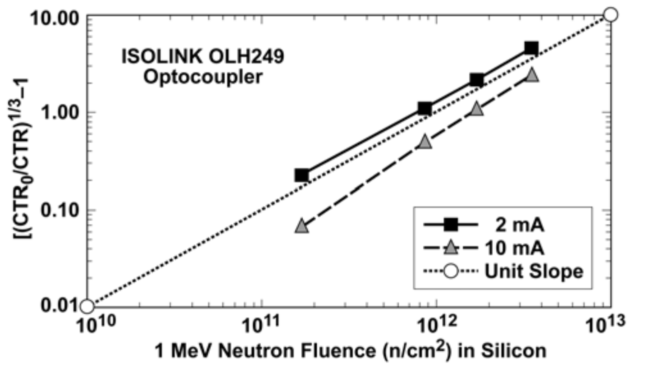

Fig. 3. Values of $[(CTRo/CTR)^{1/3} - 1]$ for $I_F = 2$ and 10 mA for OLH249.

B. *ISOCOM IS49*

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 = 1/3 for the IS49, produces Fig. 5.

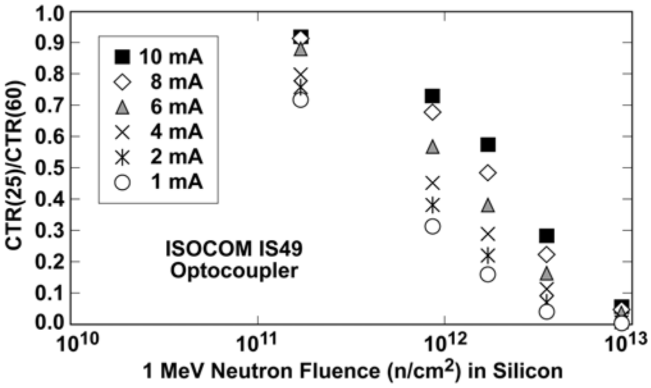

Fig. 4. Normalized CTR versus the radiation level for the IS49.

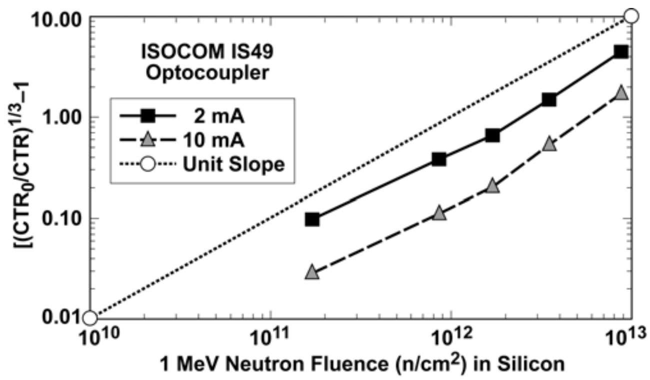

Fig. 5. Values of $[(CTRo/CTR)^{1/3} - 1]$ for $I_F = 2$ and 10 mA for IS49.

C. *ISOCOM CSM141A*

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

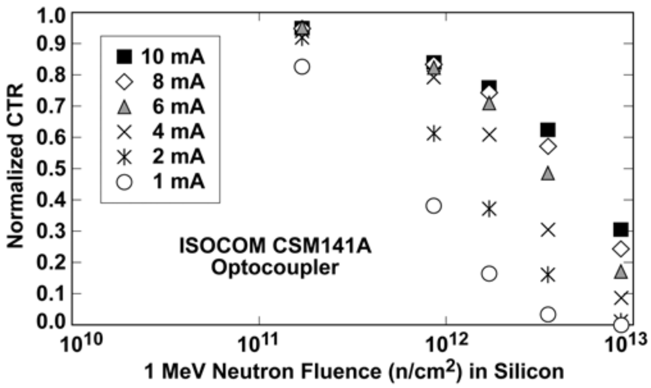

Fig. 6. Normalized CTR versus the radiation level for the CSM141A.

In Fig. 7 we compare the measured CTR at room temperature and elevated temperature of 60° C for the CSM141A. Contrary to our expectations, the measurements show very little temperature dependence. The small dependence that is seen is in the expected direction; that is, the CTR is lower at 60° C compare to CTR at room temperature.

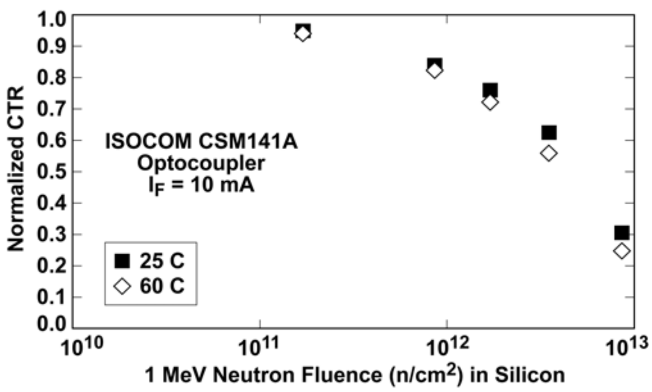

Fig. 7. Normalized CTR versus the radiation level for room temperature and 60° C for CSM141A.

The plotting format explained in the discussion of Fig. 3, and using n = 1/3 for the CMS141A, produces Fig. 8.

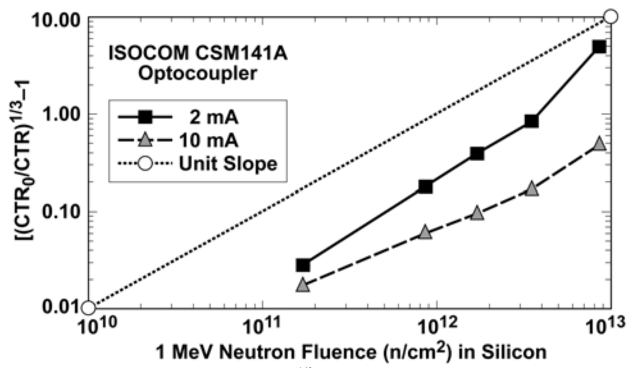

Fig. 8. Values of $[(CTRo/CTR)^{1/3} - 1]$ for $I_F = 2$ and 10 mA for CSM141A.

D. *ISOCOM CSM1800*

Fig. 9 displays the average normalized CTR (the post-irradiated value divided by the pre-irradiated value) for five

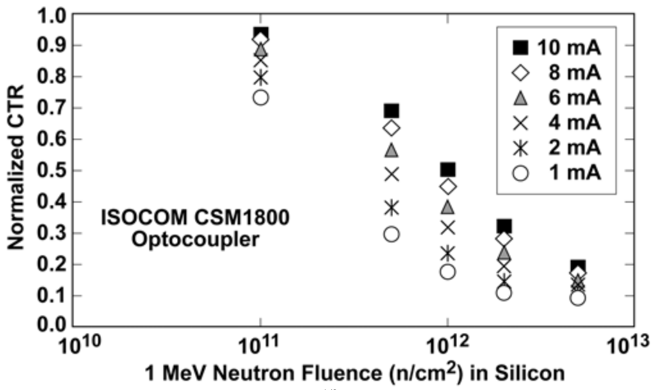

Fig. 9. Values of $[(CTRo/CTR)^{1/3} - 1]$ for $I_F = 2$ and 8 mA for CSM1800.

samples of Isocom CSM1800 versus the neutron equivalence fluences for each tested value of I_F (1, 2, 4, 6, 8 and 10 mA).

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 1/3.

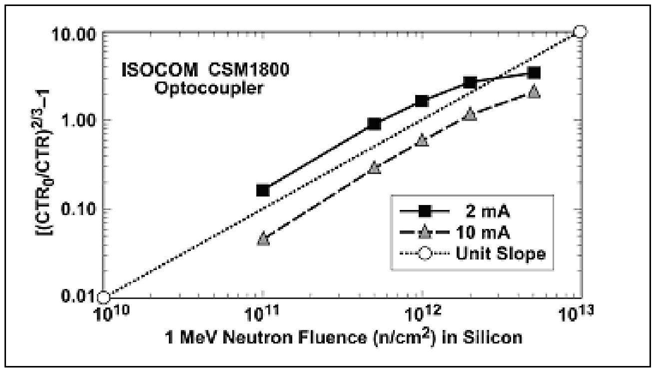

Fig. 10. Values of $[(CTRo/CTR)^{1/3} - 1]$ for $I_F = 2$ and 10 mA for CSM1800.

E. *AVAGO HCPL-5700*

Fig. 11 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).

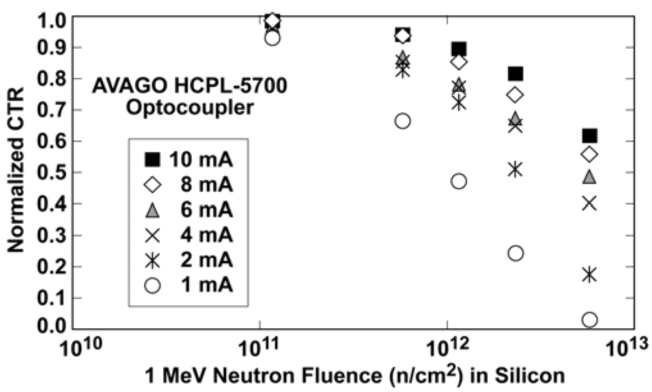

Fig. 11. Normalized CTR versus the radiation level for the HCPL-5700.

In Fig. 12 we compare the measured CTR values at room temperature and elevated temperature of 60° C for the HCPL-5700. At lower forward currents (I_F = 1, 2 and 4 mA) the CTR values at elevated temperature of 60° C are higher than the CTR at room temperature. For higher forward currents (I_F = 8 and 10 mA) the CTR values at elevated temperature of 60° C are less than the CTR at room temperature.

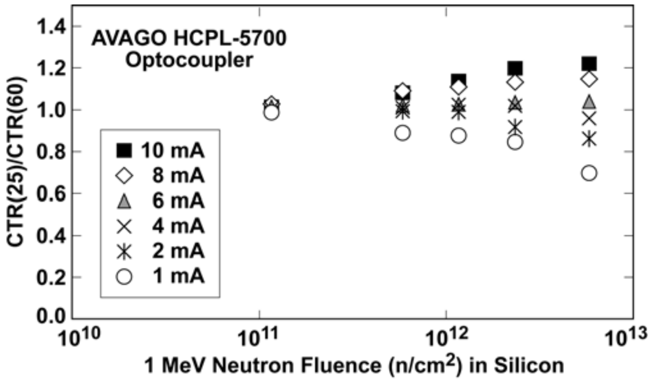

Fig. 12. Ratio of the CTR at room temperature relative to 60° C versus the radiation level for the HCPL-5700.

The plotting format explained in the discussion of Fig. 3, and using n = 2/3 for the HCPL-5700, produces Fig. 13.

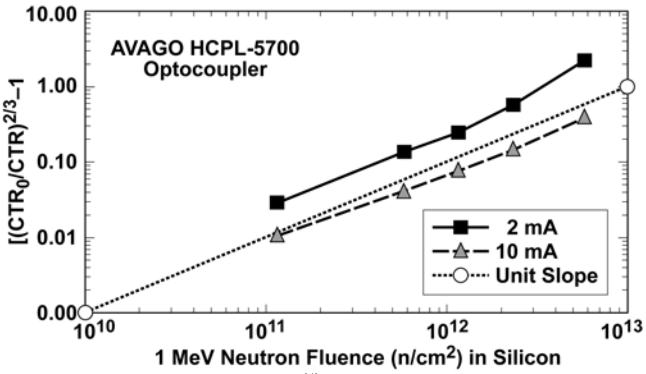

Fig. 13. Values of $[(CTRo/CTR)^{2/3} - 1]$ for I_F = 2 and 10 mA for HCPL-5700.

V. CONCLUSION

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

In Fig. 14 we compare measured CTR values for I_F = 10 mA for Isolink OLH249, Isolink OLS049, Isocom IS49, Isocom CSM141A, Isocom CSM1800 and Avago HCPL-5700 together. The OLH249 and IS49 are electrically identical to JEDEC registered 4N49 optocoupler. The Isocom IS49 clearly has much less degradation compared to Isolink OLH249. The IS49 CTR degradation is about 50% at I_F = 10 mA compare to 90% degradation for OLH249 at 2 x 10^{12} 1-MeV neutron fluence. The IS49 has a double heterostructure doped LED and OLH249 also has an internal heterostructure doped LED. It has been shown that the LEDs which are doped heterostructure, show far less damage by radiation. Therefore, most likely the poor performance of OLH249 is due to degradation of the internal photo-transistor.

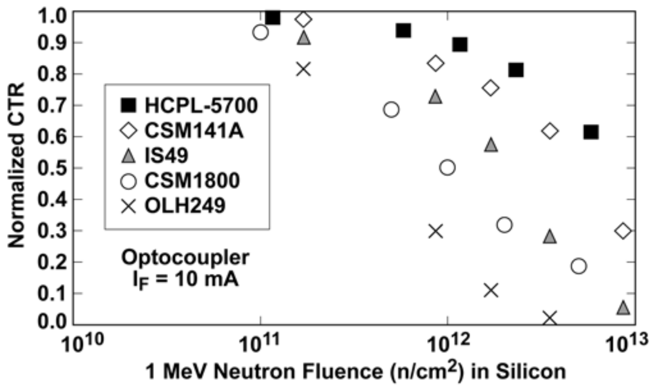

Fig14. Comparison of normalized CTR for OLH249, IS49, CSM141A, CSM1800 and HCPL-5700.

The Isocom CSM141A also shows much better CTR degradation characteristics due to radiation exposure. The CTR is about 65% at I_F = 10 mA for 3 x 10^{12} n/cm^2.

The Avago HCPL-5700 is electrically identical to JEDEC registered CSM141A optocoupler. The HCPL-5700 CTR degradation is about 81% at I_F = 10 mA for 2 x 10^{12} n/cm^2. The operating margin of optocouplers is considerably lower when they are used at low forward current. Although the low forward current helps LED reliability, using an optocoupler with low forward current makes the overall performance more dependent on amplification of the reduced photocurrent by the phototransistor. This reduces the overall operating margin, increasing the sensitivity of the part to small changes in phototransistor properties, such as leakage current, or gain reduction due to impurities or water vapor.

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, which has not already been accounted for in this study.

VI. REFERENCES

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