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Radiation Immunity of Agilent Technologies Optocouplers

Application Note 1023

Introduction

This application note describes the immunity of Agilent Technologies optocoupters to the effects of high radiation environments, such as those encountered in military and space applications. According to MIL-HDBK-279,

> "Optical isolators (i.e. optocouplers) are a combination of a GaAs LED and either a photodiode or phototransistor. The isolators containing phototransistors are more sensitive to irradiation than those containing photodiodes." [1]

Agilent optocouplers use photodiodes, whereas many optocouplers use phototransistors in their designs. Several Agilent optocouplers have been exposed to high levels of neutron fluence and gamma radiation. The results of these tests, presented here, show that Agilent optocouplers are relatively immune to high radiation levels and are thus well-suited for applications where radiation hardness is desirable.

Radiation Fundamentals

An optocoupler, as any solid state electronic device, degrades in performance as a result of exposure to radiation. The extent of degradation depends upon the type of radiation encountered, as well as exposure level and duration.

Radiation Types: Particles and Photons

There are two basic types of radiation: particles and photons. Particles (neutrons, protons, and electrons) have mass, energy, and sometimes charge. Photons (gamma rays, x-rays) are bundles of electromagnetic energy with no mass or charge. Particle radiation is measured in terms of fluence (particles/area), whereas photon radiation is measured in terms of total dose (rads [Si]) and dose rate (rads[Si]/sec). One rad is the radiation absorbed dose which releases 100 ergs of energy per gram of absorbing material, in this case silicon (Si).

Radiation Environments: Space and Military

Radiation environments typically consist of both particles and photons. Natural space radiation contains high-energy gamma rays, Van Allen protons and electrons which combine to give a significant total dose over time. Maximum fluences are 10^4 protons/cm^2 (3 rad/hour equivalent) and 10^{10} electrons/cm^2 (100 rad/hour equivalent).[2] in contrast, military radiation environments caused by a nuclear blast last less than one microsecond. Huge neutron fluences (10^{12} neutrons/cm^2) and gamma ray dose rates of 10^9 rads [Si]/sec characterize this environment.[3]

Radiation Damage: Displacement and Ionization

The ability of radiation to penetrate matter and cause damage varies as a function of mass, energy, and charge. Neutrons and protons have more mass than electrons and are therefore more harmful. Radiation occurs over a broad spectrum (Figure 1), but energies of 0.1 MeV or greater cause significant damage. Charged particles (protons, electrons) have much shorter penetration depths than do neutrons and gamma rays of the same energy. Neutrons are largely responsible for permanent displacement damage in optocouplers, whereas transient ionization damage is mostly due to gamma radiation.

High-energy neutrons strike and displace atoms from their normal positions in the crystal lattice, resulting in a vacancy and an interstitial atom. These defects are equivalent to semiconductor

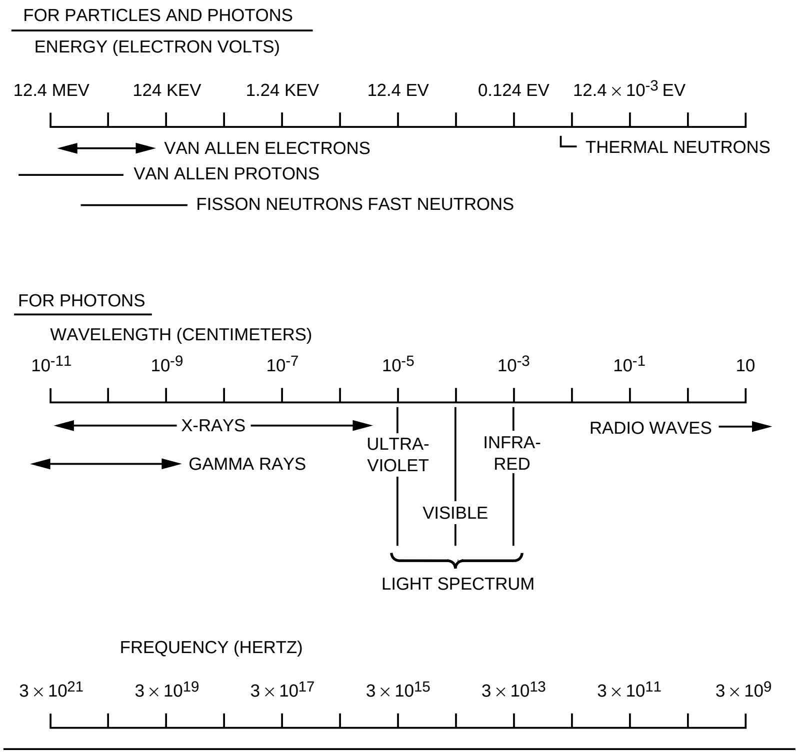

Figure 1. Radiation Spectrum Nomograph

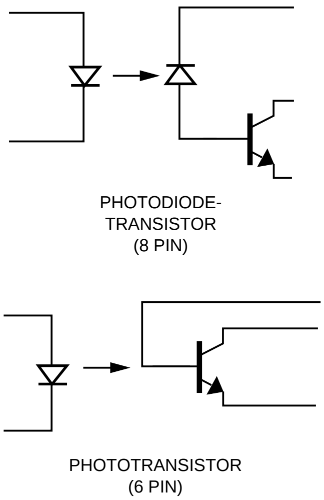

Figure 2. Photodiode and Phototransistor Optocoupler Schematics

impurities; they have energy levels in the forbidden gap and can act as recombination centers.[4] Consequently, carrier lifetimes decrease and the material's effective resistivity increases. These effects combine to impair device performance in a permanent way. In optocouplers, fluences above 10^{12} neutrons/cm^2 lead to dimmer LEDs, reduced optical channel transmittance, decreased photodiode efficiency, and less transistor gain.[5]

High-energy gamma rays impart energy to electrons (and holes) in the crystal lattice, exciting them to nonequilibrium (ionized) states. During exposure, photocurrent surges are produced in the depletion regions of reverse-biased pn junctions. These surges are dose rate dependent and can induce an erroneous high ("off") to low ("on") output transition. At dose rates above 10^9 rads(Si)/sec, photocurrents in the 1 - 1000 mA range occur which can cause device latch-up and burn out. At all dose rates, the accumulated total dose leads to noticeable (but not irreversible) degradation. Total doses as low as 10^4 rads(Si) can impair optocoupler performance through increased leakage currents.[6]

Optocoupler Radiation Response

Radiation tests have been performed on a variety of Agilent optocouplers under a wide range of conditions over the last ten years. In every case, the primary conclusion is that the Agilent photo IC design yields superior immunity to high radiation levels.

Figure 2 illustrates the difference between photodiode and phototransistor style optocouplers. The former distinguishes the optical detection and amplification functions with separate photodiode and transistor stages. This design permits shallower diffusion depths and a smaller transistor base area. Phototransistor optocouplers, on the other hand, maximize the base area for increased optical coupling. This scheme makes the device very susceptible to radiation. At the same radiation level, the device with the smaller exposed sensitive area will experience less radiation damage and hence perform better.[7]

CTR (Current Transfer Ratio) is a convenient figure of merit for measuring optocoupler performance. It is defined as the ratio of output collector current (I_O) to input forward LED current (I_F) expressed as a percent. A handy overall transfer characteristic, it gives us the device gain in the "on" state. We will examine CTR degradation, calculated as change in CTR (final CTR – initial CTR) divided by the initial value. Agilent hermetic optocouplers exhibit no significant operation-impairing CTR degradation due to radiation at the following levels: [8]

1. **6N134** (dual channel logic gate, 400% typ. CTR, 10 mA I_F)
Gamma Total Dose:
3.0 x 10^3 rads(Si) (+)
Neutron Fluence:
4.0 x 10^{12} neutrons/cm^2 (+)

2. **6N140** (quad channel split Darlington, 300% min. CTR, 0.5 mA I_F)
Gamma Total Dose:
3.5 x 10^3 rads (Si)
Neutron Fluence: 4.0 x 10^{12} neutrons/cm^2 (*)

3. **4N55** (dual channel single transistor, 9% min. CTR, 16 mA I_F)
Gamma Total Dose:
3.0 x 10^3 rads(Si) (+)
Neutron Fluence:
4.0 x 10^{12} neutrons/cm^2 (*)

All results were obtained with the minimum recommended input forward LED current (I_F). The devices were exposed to three successively increasing gamma dose rate and neutron fluence levels. The highest gamma dose rate levels were 4.0 x 10^9 rads(Si)/sec for the 6N134 and 4N55, and 2.0 x 10^{10} rads(Si)/sec for the 6N140. An asterisk (*) indicates the observed upper limit to optocoupler radiation immunity, defined as the level beyond which the device cannot be expected to perform reliably. A plus (+) indicates that the level cited was obtained through extrapolation of the linear degradation trend to the immunity limit. Total dose degradation is dose-rate dependent, so at lower dose rates, such as those encountered in space applications, the gamma total dose limit will be significantly higher.

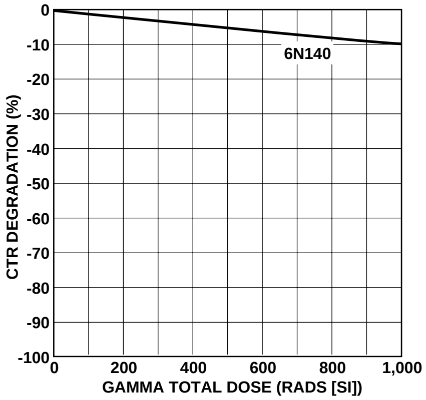

Figure 3. Agilent Optocoupler Gamma Radiation Response

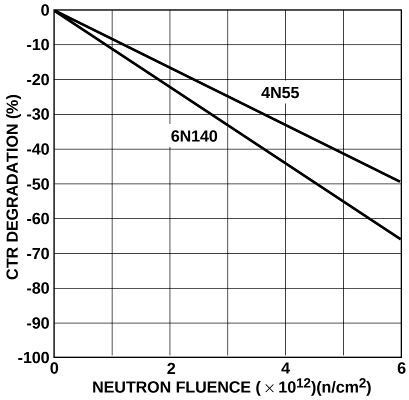

Figure 4. Agilent Optocoupler Neutron Fluence Response

Figures 3 and 4 illustrate the radiation performance of the 6N140 and 4N55. As expected, neutrons cause more severe and permanent damage than gamma rays. Performance degrades with increasing radiation level. At the same radiation level, CTR degradation is more pronounced at lower drive current (I_F).

This data reinforces our confidence in the Agilent optocoupler design as intrinsically superior in terms of radiation hardness. With shallower photodiode and transistor base diffusion depths than those of phototransistor optocouplers, the Agilent device minimizes the capture volume exposed to harmful radiation.

Table 1 shows the US Government RHA (radiation hardness assurance) levels for JAN qualified Class B (military) and Class S (space) microelectronic devices.[9] Levels M and D generally apply to military components, whereas levels R and H are important for devices used in space applications. The radiation data presented would lead us to conclude that Agilent hermetic optocouplers perform adequately up to and even beyond the above RHA neutron fluence levels. Immunity to harsh neutron radiation causes us to expect the devices to pass RHA total dose levels as well. In fact, MIL-HDBK-279 states that “in general, optical isolators are within manufacturer’s specification to 10^6 rads.” [10]

Table 1. Radiation Hardness Assurance Levels

RHA Level Designator	Radiation and Total Dose (rads)	Level of Neutron Fluence (n/cm^2)
/	No RHA	No RHA
M	3000	2 x 10^{12}
D	10^4	2 x 10^{12}
R	10^5	1 X 10^{12}
H	10^6	1 X 10^{12}

Conclusion

In summary, Agilent optocouplers offer superior immunity to the effects of a variety of high radiation environments, making them a logical choice for military and space applications where radiation hardness is desirable. We wish to thank the staff of the Nuclear Weapons Effects Laboratory of White Sands Missile Range, White Sands, New Mexico, for their support.

Appendix

Military Documents Relating to Radiation Testing and Device Qualification

1. MIL-STD-883C, "Test Methods and Procedures for Microelectronics", 25 Aug. 1983.
Group E: Radiation Hardness Assurance Tests
Method 1017.2, Neutron Irradiation
Method 1019.2, Steady State Total Dose Procedure

2. MIL-HDBK-280, "Neutron Hardness Assurance Guidelines for Semiconductor Devices and Microcircuits", 1984.

3. MIL-HDBK-279, "Total-Dose Hardness Assurance Guidelines for Semiconductor Devices and Microcircuits", 1984.

4. MIL-M-38510F, "Military Specification Microcircuits, General Specification for", 31 Oct. 1983.

Notes and References

1. MIL-HDBK-279, 1984, p.41.

2. Myers, David K., "Space and Nuclear Environments and Their Effects on Semiconductors", *Electronic Engineer*, Sept., 1967

3. Rose, Marion, "Nuclear Hardening of Weapons Systems" (Parts I, II, and III), *Defense Electronics*, Sept., Oct., Nov., 1979.

4. Grove, Andrew S., *Physics and Technology of Semiconductor Devices*, Wiley, 1967, p.143.

5. Tirado, Joseph, "Rad-Tolerant ICs Are Available Off The Shelf", *Defense Electronics*, Dec., 1984, p.56.

6. Soda, K.J., Barnes, C.E., Kiehl, R.A., "The Effect of Gamma Irradiation on Optical Isolators", *IEEE Transactions on Nuclear Science*, Vol. NS-22, No. 6, Dec., 1975, p.2475.

7. Epstein, A.S., and Trimmer, P.A., "Radiation Damage and Annealing Effects in Photon Coupled Isolators", *IEEE Transactions on Nuclear Science*, Vol. NS-19, p.391.

8. Radiation data courtesy of the Nuclear Effects Weapons Laboratory, White Sands Missile Range, White Sands, New Mexico.

9. MIL-M-38510F, p.11.

10. MIL-HDBK-279, p.41.

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Data subject to change.

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