Radiation Hardened Performance of Discrete Semiconductor Products

by Kent Walters

System designs often require radiation hardness assurance for semiconductor products. In earlier years this primarily dealt with military programs, but has now evolved to numerous communication satellites exposed to radiation belts while orbiting the earth.

The most common form of radiation in space is from solar electromagnetic radiation or total ionizing dose (TID) effects over a period of time. However other radiation can be of concern particularly in small subcomponents of integrated circuits (ICs). For example, radiation can include single event effects (SEE) with heavy ions or charged particle strikes. These may produce collected charge at sensitive node regions in ICs that would impact normal operation. Also single-ion induced events within a MOSFET can result in "single-event gate rupture" (SEGR) and failure particularly for DMOS or EPROMs. Logic circuits can also experience single-event upset (SEU) or in other cases single-event latch-up (SEL) as a result of a parasitic silicon controlled rectifier (SCR) structure in an IC becoming energized by an ion strike.

Despite these type radiation effects, many discrete semiconductors can be characterized simply by TID effects to ensure satellite mission life. This also offers program managers and circuit designers a quick overview in performance for many discrete products for radiation hardened space system design. Requirements have historically been specified in TID of 10^3 to 10^6 rads(Si) or 1 krad to 1000 krad(Si) depending on the satellite orbit and shielding. It should also be noted the industry standard for measuring TID is now in terms of the Gray (Gy) where 1 Gy = 1 J/kg = 100 rad(Si), and rad(Si)/100 = Gy. For example, 1000 krad(Si) or 10^6 rad(Si) now becomes 10 kGy.

In those cases where it may also involve nuclear weapon survivability, it can additionally include neutron irradiation and prompt dose rate testing. The latter can determine if prompt ionization current effects are excessive to trigger SCRs or damage sensitive components such as integrated circuits lacking transient protection.

Many of the silicon p-n junction diode products provided by Microsemi with passivated die in hermetic packages are inherently hard for these radiation levels generally observed in satellite applications and military requirements. Much of this insight has been acquired with accumulated data over the last 40+ years. However some diodes as well as other discrete product types deserve caution. These distinctions are further outlined as follows.

Rectifiers are typically observed as radiation hard up to 10^6 or 10^7 rads(Si) and 10^{14} n/cm^2. This performance is dependent on the rectifier breakdown voltage (V_{BR}) as well as pre and post irradiation requirements in application. Forward voltage (V_F) and reverse leakage current (I_R) eventually become excessive beyond these radiation levels, particularly for higher voltage rectifiers beyond a few hundred volts. The "fast" and "ultrafast" rectifiers will have lesser effect from high radiation with their shorter minority carrier lifetime features and epitaxial designs to minimize forward voltage. This may offer further advantage in some high radiation applications.

Zeners and transient voltage suppressors are very radiation hard with majority carrier avalanche breakdown voltage regulation. These easily perform up to 10^7 rads(Si) and 10^{14} n/cm^2 for products up to 200 volts. Below 100 volts, they exceed 10^8 rads(Si) and 10^{15} n/cm^2.

Schottky rectifiers also operate on a majority carrier principle with radiation hard performance. However precautions may be necessary with SEE particularly with higher voltage SiC devices.

Special considerations may also be needed for zero-TC reference diodes that specify very small voltage change (typically in mV) versus temperature for critical circuit references. Minority carrier lifetime killing effects from radiation can influence the reference voltage stability particularly since there are forward biased p-n junction(s) in series with a Zener for their zero-TC features (see MicroNote 205). With these considerations, Microsemi has designed reference diodes with hardened performance features up to 10^6 rads(Si) and beyond. Many of these example devices have JAN, JANTX, JANTXV qualifications or JANS equivalent screening. It should also be noted that Zero-TC reference diodes are one of the only diode products identified with radiation hardened options in military slash sheet specifications since most other diodes are inherently radiation hard.

Microsemi also provides silicon controlled rectifiers (SCRs). These are not radiation hard beyond 10^5 rads(Si) and 10^{11} n/cm^2 except when specifically designed for that purpose. Examples include the 2N3027 to 2N3032, which are radiation tolerant. Also the GA100, GA101, and GA102 devices are specifically radiation hardened up to $3x10^{14}$ n/cm^2 and 10^7 rads(Si) or higher depending on parametric requirements. Details on these and other devices are further described in product data sheets.

Microsemi also has numerous bipolar transistor and MOSFET products including many that are military qualified with various radiation hardness levels as defined in MIL-PRF-19500. Examples include special designs for the 2N2369 transistors that have been demonstrated radiation hard to the demanding Rockwell Peacekeeper Program. Other types such as 2N5153 and 2N5154 are also available that have generic data demonstrating radiation tolerant performance above 10^5 rad(Si) if operated at IC collector currents within their specified min-max range. When n-p-n or p-n-p standard discrete transistors are operated at relatively low I_C current values, they deserve caution in current gain or h_{FE} performance where they are not considered as radiation tolerant. The latest Microsemi qualified products can be found in the QPDSIS-19500 database primarily for the “R” and “F” radiation levels of 100 krad(Si) and 300 krad(Si) respectively.

Other investigations such as reported by A.H Johnston, et al, at JPL, have found n-p-n devices degrade far more than p-n-p discrete transistors. Devices with high collector-base voltage ratings degrade far more than those with low voltage ratings. Also less damage or degradation occurs at high current densities than at low currents. Wide variations in the total dose hardness of discrete transistors can occur with nearly identical geometries from different manufacturers. Very few devices degrade much below 10^4 rads(Si) while most transistors will degrade significantly at levels of approximately $5x10^4$ rad(Si) or more. The primary parameter affected by radiation is gain loss. Circuits that are designed to be less critical to gain losses are also less sensitive to radiation affects.

The rapidly growing PIN diode product line at Microsemi offers circuit designers a highly efficient means of radio frequency (RF) signal switching. These devices operate with very long minority carrier lifetime in their intrinsic or "I" region for overall RF frequency range performance. Lifetime killing effects from radiation will eventually compromise the lower operating frequencies of these diodes. Although little radiation data is available on PIN diodes, it is still anticipated that moderate levels of total dose radiation up to 10^4 to 10^5 rads (Si) can be absorbed without severely impairing RF parametric switching performance, particularly at higher frequencies.

The UM9441 is a good example of a PIN diode that has been characterized in radiation response. When reverse biased, it is specified for nuclear and electromagnetic radiation detection including gamma, electrons, and X-rays of 10^5 to 10^8 rads. Since PIN diodes are seeing greater use in new RF applications for replacing reed relays (including 1 GHz or more), a further interest in characterizing them in radiation response may be anticipated. Microsemi welcomes R&D evaluation opportunities with PIN diodes (or any other product) in radiation environments where overall high reliability is essential.

Microsemi has been involved for over 50 years in numerous military programs involving radiation hardened product specifications with stringent performance requirements. This also includes the largest selection of JANS qualified products in the world including surface mount package options. The Microsemi web site at www.microsemi.com also includes more of this information with further updates on radiation hardened discrete bipolar transistors and MOSFETs. In addition to discrete products, Microsemi also offers a variety of radiation tolerant products for ICs, field programmable gate arrays (FPGAs) and Hybrids.