Radiation-Hardened Power Transistors

Solid-state devices intended for use in applications such as space satellites or military-weapons systems must be able to survive various types of radiation without significant changes in performance characteristics. The damaging types of radiation most likely to be encountered include neutron bombardment, gamma rays, flash x-rays, and electromagnetic pulses (EMP).

TYPES OF RADIATION

Neutron radiation can be particularly harmful to discrete or monolithic bipolar transistors. Fast-neutron bombardment can cause displacement of atoms from the silicon crystal lattice of a transistor; these atoms trap out charge carriers and increase the recombination rate of charge-carrier pairs. As a result, the lifetime of minority carriers in the transistor base region is shortened (causing a decrease in current gain), the collector series resistance rises (causing higher collector saturation voltage), and transistor leakage currents increase. Current gain is affected most rapidly and most critically, and is the chief cause of failure in devices exposed to neutron radiation.

Because neutron displacement damage results primarily in a shortening of minority-carrier life-time, its effect is minimal on MOS transistors (both discrete and monolithic) because they are majority-carrier types.

Gamma rays produce large numbers of hole-electron pairs in solid-state devices. When these charge-carrier pairs recombine, they generate a current (called a "photocurrent") which may be large enough at high gamma dose rates to turn on a transistor. The photocurrent then experiences a step-function increase as a result of the transistor gain. The increased current (or secondary photocurrent), which may exceed device ratings, lasts for a period equal to the gamma-ray exposure time plus the turn-off time of the transistor.

Photocurrents produced by gamma-ray ionization can cause latch-up, circuit ringing, or junction breakdown in all types of transistors.

Flash x-rays and electromagnetic pulses produced by a nuclear explosion can cause permanent physical damage to any type of solid-state device. Flash x-rays generate a thermomechanical shock that propagates through the dense material (molybdenum, gold, or copper) used for lead connections and for bonding the pellet to the header. At high energy levels (above 10 kev), the shock wave can be strong enough to fracture the pellet.

Electromagnetic-pulse (EMP) radiation can induce extremely high voltage pulses in the cables used to interconnect electrical equipment. If these voltage pulses exceed the junction-breakdown capability of a solid-state device, they can cause junction avalanching and result in device destruction.

The effects of flash x-rays and EMP radiation cannot be overcome by any changes in device design and processing, but must be treated as system-design problems. The chief weapons used to prevent x-ray or EMP damage are the traditional methods used to combat any RFI: shielding and line-filtering.

RADIATION-HARDENING TECHNIQUES

RCA offers a variety of bipolar silicon power transistors in which special design and processing techniques are used to assure continued functional performance after exposure to specified dosages of neutron and gamma radiation.

Neutron-Radiation Compensation—In RCA radiation-resistant power transistors, the base width is made as narrow as possible (consistent with other design objectives) to achieve a minimum base transit time so that a maximum number of minority carriers can complete the journey through the base. The narrower base width thus compensates for the major cause of failure in transistors exposed to neutron radiation, the reduction in minority-carrier lifetime and the corresponding decrease in transistor current gain. The voltage-supporting region in the collector is also made as narrow as feasible and is heavily doped. In this way, the series-resistance path is made as low as possible to compensate for the rise in collector series resistance and the resulting higher saturation voltage caused by exposure of the transistor to neutron radiation.

The problem of increased leakage currents is solved by use of epitaxial-planar transistors. The initial leakage in these transistors is so small that even the higher levels caused by neutron bombardment are unlikely to cause failure.

Because the narrower base width and reduced collector resistivity used to improve transistor radiation resistance are contradictory to the design requirement for high-voltage, high-energy transistors, designers should adjust circuits to require the minimum possible emitter-to-collector voltage-breakdown capability. In addition, ratings for transistors should be specified in accordance with the way in which the devices are to be used (i.e., V_{CER} or V_{CEV}, and never V_{CEO}). The circuit design should also provide high-energy protection for the transistor.

Gamma-Radiation Compensation—The gamma dose rate at which the onset of secondary photocurrent occurs depends strongly on the geometry of the transistor emitter. The secondary photocurrent is initiated when a portion of the emitter-base junction becomes forward-biased because of the voltage drop across the lateral base resistance under the emitter. In RCA radiation-resistant transistors, the distance from the base contact to the farthest point of the base under the emitter is reduced to the minimum possible value to achieve a substantial increase in the gamma threshold level at which the secondary photocurrent starts. Table XXXI shows RCA's radiation-hardened power transistors.

Table XXXI - RCA Radiation-Hardened Power Transistors

Parent Type	Military Specification Type	MIL-S-19500/ Specification
Epitaxial-Base Types		
2N6248		—
High-Speed Types		
2N3879	JAN2N3879, JANTX2N3879	526
2N5038	JAN2N5038, JANTX2N5038	439
2N5320		—
2N5322		—
2N5672	JAN2N5672, JANTX2N5672	488
2N6480		—
High-Voltage Types		
2N6673		536
2N6688		—