

## **How Rad Hard Do You Need? The Changing Approach To Space Parts Selection?**

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### **Introduction**

Traditional radiation hardened or “rad hard” parts are generally considered to be capable of withstanding the most severe space environments. In fact, these devices are designed and fabricated with the specific goal of enduring the harshest space radiation environments. And while they have tremendous radiation capabilities, these parts are more expensive and less advanced than today’s commercially available components. As a result, the main customers for these ICs have generally been well-funded military and scientific entities.

However, a migration from traditional rad hard components is currently underway, thanks to the commercialization of space. Space is no longer the sole domain of the world’s largest governments, where programs are funded by enormous and eternal budgets aimed at fighting the cold war. Consequently, space manufacturers around the world are faced with a requirement to build satellites that are faster, better and cheaper than those made in the past.

To meet this rapidly changing market, satellite companies and component manufacturers alike have begun reshaping their product offerings. More specifically, semiconductor manufacturers have begun reinterpreting industry conventions to meet the needs of their newly redefined customer base. And, while they only comprise 5-10% of the overall cost of a satellite, electronic components can nevertheless provide significant savings to a system’s total price tag if they are procured at a reduced rate. As a result, the traditional, rigid definition of “rad hard” is slowly being replaced by the question, “How rad hard do you need?”

### **Radiation Effects on Semiconductors**

Unlike their commercial counterparts, satellite systems designers are severely limited by the number of components they have at their disposal. A commercial system has a plethora of different manufacturers to which they can turn for a solution. For example, there are over 20 different commercial manufacturers of SRAM memory. Each manufacturer offers a variety of depths, widths, speeds and voltages. On the other hand, there are only 6 manufacturers of SRAM specifically designed for use in space.

The space environment itself engenders the disparity between available vendors in commercial- and space-based designs. Space is a highly radioactive environment, the effects of which essentially destroy the functionality of most commercial ICs. There are four primary causes of this radiation: trapped electrons, trapped protons, solar protons and cosmic rays.

Trapped electrons are negatively charged particles that are relatively low in mass, but they are also extremely energetic. Due to their small masses, they are typically found in very high orbits such as the Geosynchronous orbits (or GEO orbits) that are approximately 36,000 km above the earth.

Trapped protons are positively charged particles held captive by a planet's gravitation field. They are less energetic than electrons, but they are approximately 2000 times more massive than electrons. They exist in high concentrations at low altitudes. For example, Low Earth Orbits (LEOs), such as those located 1400km – 2000km from the earth's surface, are proton-dominated orbits.

Solar protons are similar to trapped protons except they are ejected from the Sun during a solar flare event and are therefore not trapped in the planet's gravitation field.

Cosmic rays are the final source of natural space-borne radiation. They are comprised of alpha particles, heavy ions and protons. Heavy ions are the primary concern when considering the effects of cosmic rays on semiconductors because these massive, highly charged particles can cause severe damage to devices.

How trapped protons, trapped electrons, solar protons and cosmic rays interact with semiconductor components is generically called radiation effects. These effects can be broken down into three broad categories: Total Ionizing Dose (TID), Single Event Latch-Up (SEL) and Single Event Upset (SEU).

When an energized particle impacts a semiconductor, it deposits a small electrical charge to the silicon. The charges often migrate off of the semiconductor, but over time they eventually build up on the device. Once the part has accumulated enough excess charge, it will cease to function. Total Ionizing Dose is the amount of radiation or energy that a semiconductor can absorb before it stops functioning. It is measured in rad(Si), or radiation absorbed relative to silicon. TID tolerance is based on the process used to fabricate, and the methods used to design, the semiconductor.

Single Event Latch-Up, measured in mega electron volts (MeV) and dependent on a part's design, occurs when a highly charged particle imparts so much energy to a semiconductor that the device's current is dramatically driven out of specification. The device is said to have "latched-up" if it stays in this heightened state. At best, the part remains inoperable until it has been reset. At worst, it will become so hot that it will actually melt down and destroy itself.

Single Event Upset, which is also measured in MeV, takes on different meanings for digital parts and analog parts. In digital parts, SEU occurs when a highly charged particle impacts a memory cell and alters the cell's charge, essentially changing a 0 to a 1. In analog parts, a momentary spike is seen on a device's output. Regardless of the part type, SEU is a nondestructive, recoverable event that can be mitigated in a number of ways. Designers are typically most concerned with SEU in memory devices because a SEU event corrupts stored data. Like SEL, SEU is dependent on a device's design.

	TID	SEL	SEU
Commercial ICs	3-30 krad(Si)	1 - 120 MeV	1 - 120 MeV
Radiation-Enhanced ICs	Customized to Orbit (100 krad(Si) Target)	Customized to Orbit (Up to 120 MeV)	Customized to Orbit (Up to 120 MeV)
Radiation-Hardened ICs	100 krad(Si) Minimum	Up to 120 MeV	Up to 120 MeV

Table 1

### Parts Available Today

Traditionally, “bulletproof” rad hard parts are defined as capable of withstanding over 100 krad(Si) of TID and are SEL and SEU immune up to 120 MeV. Beyond these minimum thresholds, definitions of TID, SEL, and SEU vary from manufacturer to manufacturer. Where one manufacturer considers a part to be rad hard if it has a TID threshold of 300 krad(Si), another company may market their part as rad hard if it only meets 100 krad(Si).

Commercial parts will have TID ranges between 3-30 krad(Si) and SEL and SEU ranges between 1-120 MeV. Of course, commercial parts are not designed with radiation performance in mind. Nevertheless, a few commercial ICs have in fact exhibited acceptable radiation hardened characteristics (i.e., over 30 krad(Si) of TID, and SEL and SEU immunity up to 120 MeV, as discussed above).

A number of new manufacturers are seeking to take advantage of these commercial diamonds in the rough. This growing group utilizes select commercial silicon to produce space worthy devices. In fact, there are several commercially-based space devices available that have either been tested for and/or modified for use in space. Their manufacturers include Maxwell Technologies and UTMC.

The technologies and approaches to space-ready a commercial device vary, but there are three general methods used to enhance commercial parts for space. First, parts can be shielded to provide enhanced total dose protection. Maxwell Technologies encapsulates already radiation-tolerant commercial parts in a patented package technology, called RAD-PAK®. This package actually incorporates a scientifically calculated amount of shielding directly into the electronic package.

Another approach, which is used by UTMC in a propriety process, involves the refabrication of a commercial semiconductor on a radiation-tolerant process line. A third method involves building mitigation technologies into a packaged device. For example, Maxwell Technologies offers a Latch-Up Protection circuit that is designed to detect the current increases associated with latch up at the device level.

The parts that the above methods produce are generally called radiation enhanced commercial semiconductors. On a continuum measuring usability in space, radiation enhanced ICs lie between commercial and traditional radiation hardened parts. A commercial-based part might not always measure up to its radiation hardened, specialty space counterpart, but it can provide enough features that a designer will often consider its usability given its inherent cost savings and technical sophistication.

## **Strategies for Building Satellite Systems**

In the 15th century, Leonardo da Vinci wrote, "Design is inhibited by freedom and flourishes in constraint." This axiom holds true today. Designers in days gone by had to meet a very strict set of radiation requirements. All parts selected for a mission, be it military or scientific, had to be bulletproof. Period.

But thanks to the advent of commercially-based technologies and to the commercialization of space, designers now have four strategies for building satellites. With the first strategy, a designer can choose to engineer a system using only traditional rad hard parts. While it provides the best protection from radiation, this approach tends to be the most costly. It is typically reserved for highly sensitive military applications where absolute survivability is an integral part of the satellite's mission.

With the second strategy, a designer may choose to use only radiation-enhanced semiconductors. While this strategy provides a significant cost saving, there is no ideal commercially-based solution for every component inside a satellite.

The third option for designers is to use inherently radiation tolerant commercial semiconductors. This strategy saves more money than using radiation-enhanced semiconductors, but the responsibility to test and identify these parts lies solely with the satellite designer (due to the small relative size of the satellite market, no major commercial IC manufacturer appears to have a vested interest in investigating the radiation tolerance level of its parts).

The final approach to component selection is the use of commercial semiconductors without any regard for radiation tolerance whatsoever. This method is without a doubt the least expensive, but is also the one fraught with the most unknowns – and these unknowns can be disastrous to mission-critical space applications.

Since budgets are a constraint on all system designs, a combination of the first three strategies is generally used. Traditional rad hard components are designed into mission critical applications and radiation enhanced or radiation tolerant semiconductors are used in other applications. The use of commercial semiconductors without regard for radiation tolerance is typically reserved for on-board experiments, or for satellites that are themselves considered to be experiments.

The overall effect of the new market's amalgamated approach to satellite design is that designers are now asking themselves how radiation hardened their system components need to be. The International Space Station provides an excellent example of this new thought process in action. Parts on the Space Station have vastly different radiation requirements based on how critical they are to the entire system. Non-critical systems, such as experiments, are allowed SEL tolerances as

low as 14 MeV. On the other hand, mission critical systems, such as life support, have much higher SEL tolerances – as low as 37 and as high as 80, depending on the part.

Some parts even fall outside of these very general guidelines. Many Space Station systems are connected via Ethernet, much the same way that computers in an office are connected to one another. So far, Space Station engineers have not found an Ethernet device that meets the wide range of SEL and SEU tolerances. And the community is so divided over how to attack this problem that each Space Station contractor has been forced to design and implement its own Ethernet solution.

Part Number	Qty	Depth (bits)	Width (bits)	Total (bits)	Grand Total (bits)	Mass (g)	Total Mass (g)	Est. Cost Per Device	Total
A	64	32	8	256	16384	3	192	\$1,500	\$96,000
B	16	128	8	1024	16384	3	48	\$2,500	\$40,000
C	4	512	8	4096	16384	4	16	\$3,000	\$12,000
D	4	512	8	4096	16384	8	32	\$1,500	\$6,000
E	1	512	32	16384	16384	60	60	\$5,000	\$5,000

Table 2

### SRAM Case Study

Table 2 illustrates five different ways a designer can achieve a bank of 16 Mbit, or 2 Mbytes of SRAM. It shows three different traditional rad hard SRAM solutions versus two different radiation enhanced commercial semiconductor solutions.

The upper half of the table describes three standard offerings (parts A, B, and C) from traditional rad hard SRAM manufacturers. They range in size from the smallest available device, which is 256 kbit, to the largest available device, which is 4 Mbit. The lower portion of the table outlines two offerings from an enhanced commercial semiconductor supplier. Part D represents a commercially available SRAM that has been placed in a shielding package to provide additional TID protection. Part E contains five 4 Mbit commercially available SRAM plus an EDAC chip, each of which has been placed in a similar shielding package as the one applied to Part D. EDAC, or Error Detection and Correction, is used to detect and correct upset in memory parts.

Each of the three rad hard SRAM solutions fit the typical rad hard mold. That is to say, they can withstand 100 krad(Si) and are immune to SEL and SEU up at least 80 MeV. They require no additional enhancement to meet a variety of missions. Part A is a very small memory part. As such, 64 devices are needed to achieve 16 Mbits, or 2 Mbytes of memory storage. These 64 devices will easily fill most of a double-sided 6U VME memory card. In addition, they weigh approximately 192 grams and cost \$92,000 based on street estimates. Thus, aside from the fact that these parts are traditional rad hard devices, they offer the designer little benefit.

Part B is four times denser than Part A. It therefore requires only 16 devices to achieve the target memory size of 16 Mbits. While there is some cost- and mass-

reduction associated with moving to the smaller number of packaged devices, the satellite designer will still pay a lot of money (\$40,000) for the bank of memory, which takes almost one full side of a 6U VME memory card.

Part C is a relatively new type of IC now offered by several traditional rad hard vendors. It is four times more dense than Part B and 16 times more dense than Part A. There are cost and mass improvements over Parts A and B, but the satellite designer pays \$24,000 for the bank of 16 Mbits of SRAM. This solution will populate approximately 1/3 of a 6U VME card.

Part D is based on commercial SRAM die. Due to the shielded package in which it must be placed, it weighs more than Parts A, B, or C. However, the necessary bank of Part D devices will weigh less than a bank composed of Part A or Part B devices because less are needed to achieve the target density of 16 Mbits. Part D also represents a significant cost saving over any of the parts in the upper half of Error! Reference source not found. It will cost at least \$14,000 less than the traditional rad hard solutions. But because it is based on a commercial SRAM, it is highly susceptible to upset. As a result, EDAC must be used if upsets are a concern. And the cost of EDAC, which varies from application to application, must be considered when evaluating the overall price tag.

Moreover, Part D's TID tolerance is orbit-dependent. Some studies suggest that shielding is approximately 10 times more effective in electron-dominated orbits than in proton-dominated orbits. This variability requires additional engineering effort that cannot be overlooked when determining the total cost of a system. Part E, which is a multi-chip module approach, represents the most unique solution to the proposed SRAM problem. Unlike the four other proposed solutions, this device is made up of six primary active components, all within one packaged product.

Part E has four commercially available SRAM devices that are used for primary memory storage. It also has one additional SRAM die used as check bits for the EDAC, which is the sixth active component. This innovative collection of parts will appear to the system to be an SEU immune part. Consequently, the device will actually upset less frequently than the traditional rad hard SRAM. Like Part D, Part E uses a shielded package for enhancing TID survivability. But significant cost and board space savings highly recommend it; Part E will take up approximately 1/5 of a 6U VME board and save \$85,000, \$31,000, and \$15,000 over than Parts A, B, and C, respectively.

## **The Designer's Dilemma**

There are numerous techniques that can be used to design modern satellite systems. Each method has its pros and cons. Which method or combination of methods is best will be hotly debated in the years to come. The case study outlined here demonstrates the significant cost savings that can be realized when answering the question, "How rad hard do I need?" and when considering the use of commercially based parts. But commercial solutions can give ample cause for designers to be wary, despite their cost advantages. Many commercially-based space semiconductor manufacturers do not make their own silicon. This means they are dependent on other manufacturers for the very heart of their products. Large silicon manufacturers can, and do, cut off smaller suppliers in times of need. Consequently, the reasons

that make one commercial semiconductor good for space can be instantly destroyed if a manufacturer decides to alter a part for their own reasons.

Furthermore, commercially based solutions require additional engineering effort by the satellite system designer. Where traditional rad hard parts come stamped with a guaranteed TID tolerance for every mission, commercial parts need to be tested by designers before they can be incorporated into a design.

Despite these design complications, one thing is certain: space, once the regime of elite military and scientific entities, will soon become the next great commercial frontier. This means satellite systems will have to be faster, better and cheaper. The only way to achieve this is for the space community to find new and innovative approaches to its three fundamental problems – TID, SEL and SEU. As such, the space community can no longer rely solely on traditional radiation hardened components. Those who do so will most certainly lose the race. On the other hand, manufacturers who rush too quickly to the opposite extreme will lose, as well. Indeed, the numerous reported on-orbit failures of Iridium remain a constant reminder of the necessity to move cautiously towards commercial parts. In the end, the best solution undoubtedly will be a mixture of both old and new methods, with a healthy blend of the design creativity inspired by the constraining environments of a paradoxically boundless space.