Progress in Spacecraft Environment Interactions IV: Estimating Single Event Rates in High Shielding Mass Single Event Effect Environments

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Spacecraft	Device	Flight SEU/FOM SEU	Meets Success Criteria?
Shuttle Flights (STS) – 39, 48, 52, 56 (LEO)	Inmos 64K x 1 CMOS SRAM IMS1601EPI	**8**	Y (underestimates)
STS – 37, 50, 57, 51 (LEO)	Inmos 64K x 1 CMOS SRAM IMS1601EPI	**12**	Y (underestimates)
ISS – (LEO) Multiplexer de-multiplexers (MDMs)	Texas Instruments (TI) (1M x 4) CMOS DRAM TMS44400	**1 (high shield mass)** **0.3 (low shield mass)**	Y (agrees) Y (overestimates)
Engineering Test Satellite (ETS)-V geosynchronous orbit (GEO)	NEC 64K x 1 CMOS SRAM μ PD4464D-20	**0.5 (solar max)** **0.8 (solar min)**	Y (overestimates)
ETS-VI geosynchronous transfer orbit(GTO)	NEC 64K x 1 CMOS SRAM NASDA38510/91901XCR	**0.2**	Y (overestimates)
Advanced Earth Observing Satellite (ADEOS) (LEO)	Hitachi 256K CMOS SRAM NASDA38510/92001XB	**0.4**	Y (overestimates)
ADEOS (LEO)	NEC CML 4 BIT MPU NASDA38510/90201QX	**3**	Y (underestimates)
Microelectronics and Photonics Test Bed (MPTB) (GTO)	Matra Marconi Space M65656 32Kx8 SRAM	**0.94**	Y (overestimates)
Cassini Solid State Recorder (Interplanetary)	OKI 4Mb DRAM – 640/SSR	**0.12**	Y (overestimates)
Solar Heliospheric Observatory satellite (SOHO) (Interplanetary)	TI 4Mx1 DRAM SMJ44100	**0.37**	Y (overestimates)
SOHO (Interplanetary)	ATMEL CP65656EV-45 32 K x 8 SRAM	**0.09**	Y (overestimates)

Table 1. A comparison of in-flight single event upset (SEU) rates with figure of merit (FOM) predictions for eight spacecraft in flight environments ranging from low-Earth orbit (LEO) to interplanetary space (near 1 AU).

The mission objectives of NASA's Constellation Program will send crewed spacecraft well beyond low-Earth orbit (LEO) for the first time since the end of the Apollo lunar program in 1972.

Between 1972 and the present, a series of relatively massive crewed spacecraft, the space shuttle, the Russian space station Mir, and the International Space Station (ISS) were developed and operated in LEO while substantially less massive robotic spacecraft were developed and operated in a wide variety of spaceflight environments. In parallel, microelectronic technology evolved so as to make Single Event Effects (SEE) an important microelectronic reliability and qualification issue for any spacecraft. As we move beyond LEO, the natural space radiation environment becomes more severe; however, spacecraft shielding mass can be surprisingly effective at mitigating the effects of the more severe natural environment in some cases, even in the presence of secondary particle showers produced when cosmic rays interact with massive structural shielding.

In this report, we compare the in-flight performance of specific SEE-susceptible electronic components in several spacecraft, including the space shuttle, the ISS, a series of Japan Aerospace Exploration Agency robotic vehicles, the Solar Heliosphere Observatory, the Microelectronics and Photonics Testbed, and Cassini,

with predictions of SEE performance made using Peterson's figure of merit (FOM) approach. The same FOM approach is then used to estimate how SEE rates change, for the various spacecraft, as a function of changes in structural shielding mass and spaceflight environment, with the objective of demonstrating the capabilities and limitations of high shielding mass in a number of spaceflight and planetary surface radiation environments of interest to the future space exploration programs.

Table 1 shows a comparison of FOM predictions and flight data for a variety of spacecraft, microelectronic devices, and spaceflight environments. The FOM method meets the success criteria for all (estimates within about a factor of 10 greater actual), and the overestimation of shielding mass effectiveness at high shielding mass is clear for the ISS.

It is instructive to estimate the performance of ISS and shuttle in the cislunar environment using FOM. Results (table 2) suggest that SEU rates increase for both vehicles by about a factor of only 5 to 10, well within the mitigation capacity of Static Random Access Memory or Dynamic Random Access Memory error detection and corrections. Similarly, SEU rates estimated for the ISS and shuttle in LEO show that reducing the avionics shielding mass for an LEO test article can increase the observed rate to the value expected for a nominally shielded system in interplanetary space, as shown in table 3. The LEO ISS environment is, therefore, expected to be useful as a system-level testbed for interplanetary SEE effects.

Vehicle	Device	FOM LEO estimate	FOM Interplanetary Estimate
STS-48 57.1 deg. 467 km	Inmos 64K x 1 CMOS SRAM IMS1601EPI	3 per STS per day (x 10 = 30)	15 per STS per day (x 10 = 150)
STS-51 28.5 deg. 256 km	Inmos 64K x 1 CMOS SRAM IMS1601EPI	0.4 per STS per day (x 10 = 4)	15 per STS per day (x 10 = 150)
ISS – (LEO) (40g/cm2shielding) 51.6 deg. 340-360 km	TI (1M x 4) CMOS DRAM TMS44400	2 per MDM per day	27 per MDM per day
ISS – (LEO) (10g/cm2shielding) 51.6 deg. 340-360 km	TI (1M x 4) CMOS DRAM TMS44400	8 per MDM per day	94 per MDM per day

***Table 2.** Estimated change in the ISS and shuttle SEE rate ongoing from LEO to the interplanetary environment. High shielding mass mitigates the more severe interplanetary SEE environment for the nominally shielded crewed vehicle.*

Vehicle	Device	0.1 g/cm^2 shielding	0.5 g/cm^2 shielding	1 g/cm^2 shielding	5 g/cm^2 shielding
STS-48 57.1 deg. 467 km	Inmos 64K x 1 CMOS SRAM IMS1601EPI	25 per STS per day	19 per STS per day	16 per STS per day	10 per STS per day
ISS – (LEO) 51.6 deg. 370 km	TI (1M x 4) CMOS DRAM TMS44400	26 per MDM per day	19 per MDM per day	17 per MDM per day	10 per MDM per day

***Table 3.** Reducing shielding mass in LEO can result in SEE rates comparable to those expected in the interplanetary environment for the nominally shielded vehicle.*