Evaluation of System Reliability and Heavy Ion Angular Effects

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1.SSAI in support of NASA/GSFC

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Acronyms

- **Device under test (DUT)**
- **Energy (E)**
- **Error rate (λ)**
- **Error rate per bit(λ_{bit})**
- **Error rate per system(λ_{system})**
- **Field programmable gate array (FPGA)**
- **Linear energy transfer (LET)**
- **Linear energy transfer effective (LET_{eff})**
- **Linear energy transfer on set (L_0)**
- **Linear energy transfer saturation (LET_{sat})**
- **Linear energy transfer threshold (LET_{TH})**
- **Mean time to failure (MTTF)**
- **Phase locked loop (PLL)**
- **Rectangular parallel pipe (RPP)**
- **Single event upset (SEU)**
- **Single event upset cross-section (σ_{SEU})**
- **Single event upset cross-section saturation (σ_{SAT})**
- **Triple modular redundancy (TMR)**

Problem Statement

- **Field programmable gate array (FPGA) devices have become complex mixed signal integrated circuits.**
- **They are no longer as immune or resilient as their predecessors.**
- **Traditionally, there was a lot of margin regarding FPGA analysis… either very “soft” or very “hard.”**
- **We extrapolate single event upset (SEU) data to predict FPGA susceptibility to ionizing particles… predict mission failure.**
- **To properly extrapolate SEU data to complex target circuits… we need smart data!**
- **FPGA SEU testing can no longer rely on:**
  - **Simple test structures**
  - **Narrow scopes (e.g., merely configuration read-back)**
  - **Limited visibility**
- **FPGA data analysis can no longer simply rely on:**
  - **Extrapolated shift-registers**
  - **Used configuration-bits**

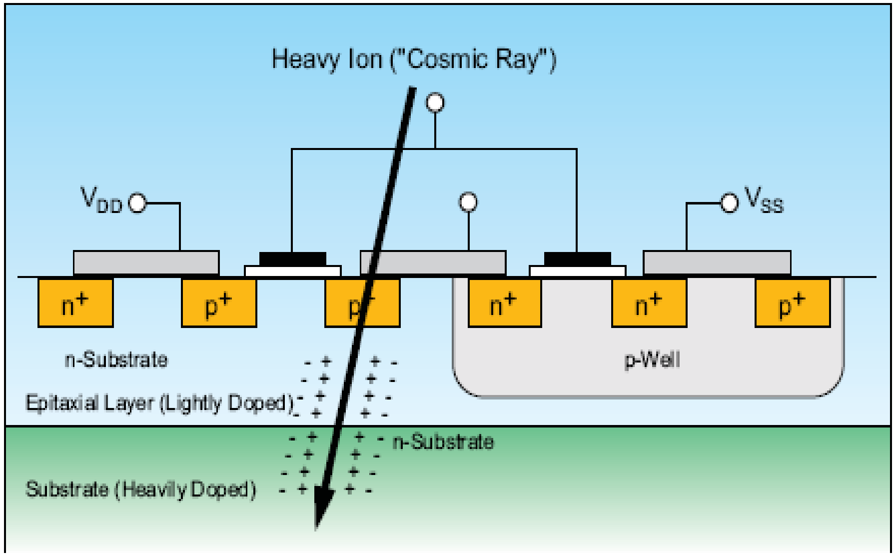
We need to test-as-we-fly and analyze-as-we-design.

Abstract

- Microsemi (Microchip) RTG4 embedded triple modular redundant (TMR) phase-locked-loop (PLL) SEU data is presented.
- SEU data analysis includes:
  - Evaluation of heavy-ion beam angular effects (rectangular parallel pipe (RPP) or no RPP)
  - Importance of finding linear energy transfer (LET) onset (L_0)
  - Comparison of prediction rate techniques

Device Penetration of Heavy Ions and Linear Energy Transfer (LET)

- **LET characterizes the deposition of charged particles.**
- **Based on Average energy loss per unit path length (stopping power).**
- **Mass is used to normalize LET to the target material.**



Average energy deposited per unit path length

$$LET = \frac{1}{\rho}\frac{dE}{dx} \quad ; \quad MeV\frac{cm^2}{mg}$$

Units

Density of target material

Characterizing SEUs: Radiation Testing and SEU Cross Sections

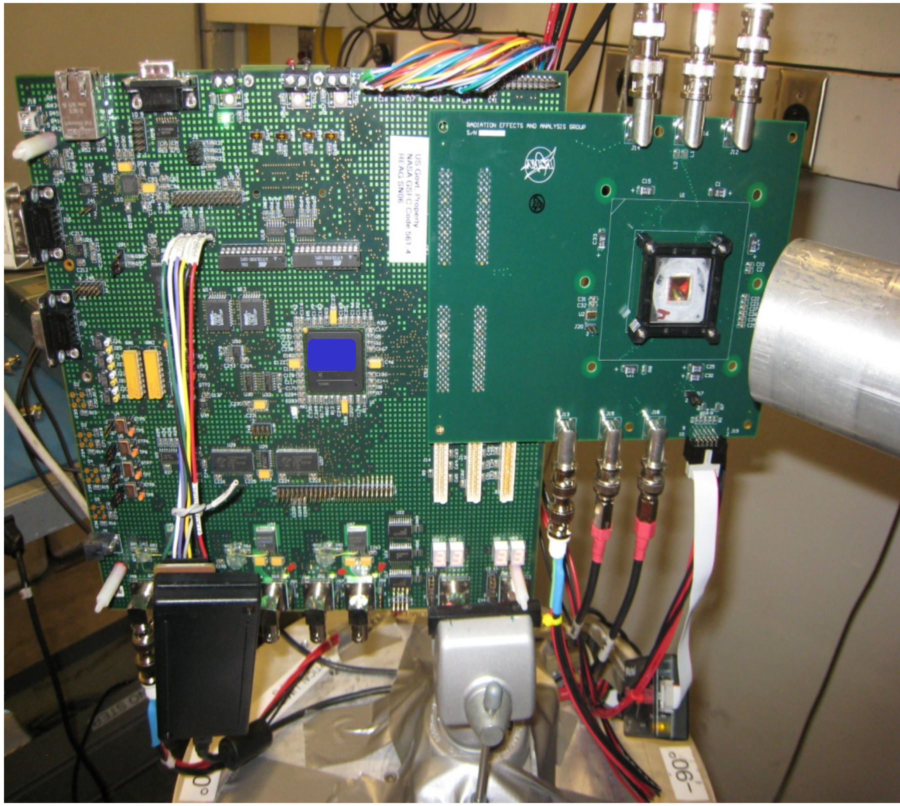
SEU Cross Sections (σ_{seu}) characterize how many upsets will occur based on ionizing particle exposure.

$$\sigma_{seu} = \frac{\#errors}{fluence}$$

Terminology:

- **Flux: Particles/(sec·cm^2).**
- **Fluence: Particles/cm^2.**

σ_{seu} is calculated at several LET values (particle spectrum).



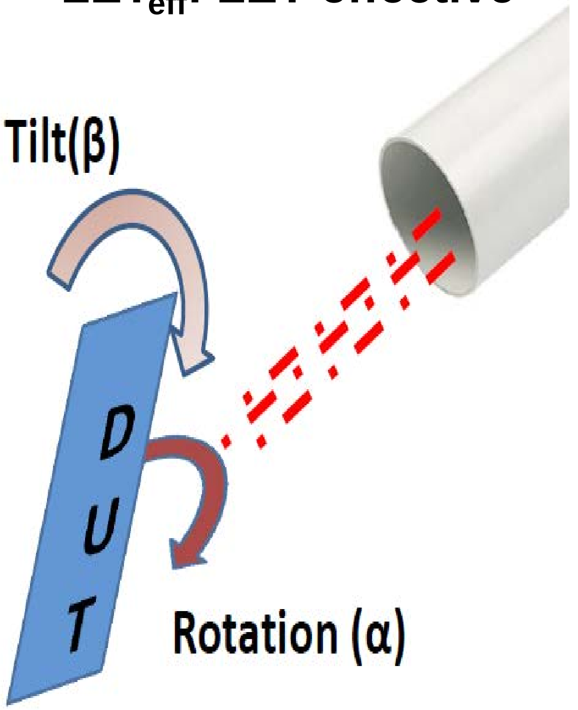
To be presented by Melanie Berg at the Microelectronics Reliability & Qualification Working Meeting (MRQW), El Segundo, CA February 5-7, 2018

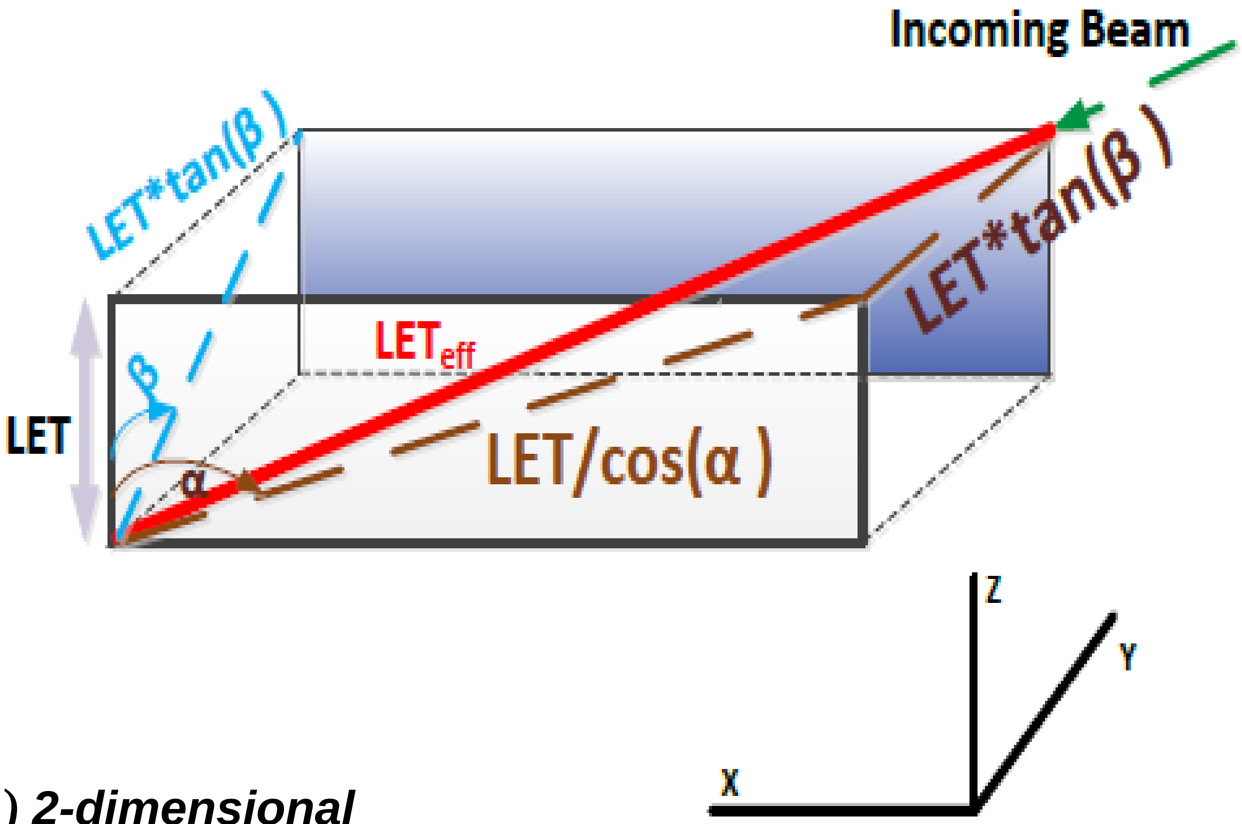
Microsemi TMR PLL in the RTG4 FPGA

- **Microsemi has added the following user design options:**
  - **Singular PLL**
  - **TMR PLL**
- **PLLs are created with analog circuitry and subsequently have a different susceptibility than other user fabric.**
- **Warning – PLL SEU data cannot be extrapolated to other user fabric data.**

RPP: Angular Effects (LET versus LET$_{eff}$)

LET$_{eff}$: LET effective



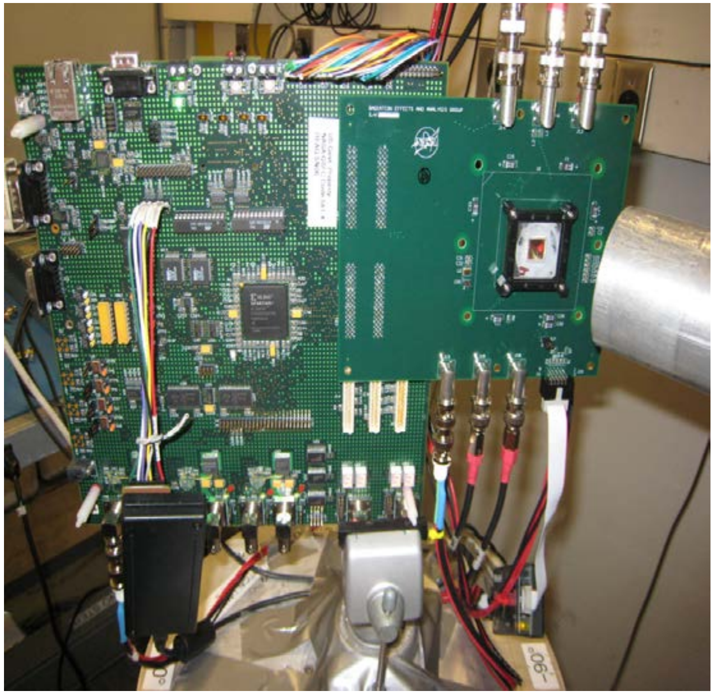


$LET_{eff} = LET/cos(\alpha)$ ***2-dimensional***

$$LET_{eff} = \sqrt{LET^2\left(tan^2\beta + \frac{1}{cos^2\alpha}\right)}$$ ***3-dimensional***

RPP and SEU Data

- As the angle of incoming beam particles deviates from normal, LET_{eff} increases.
- It is assumed that SEU cross-sections will increase accordingly.
- However, in complex systems, changing angle either:
  - Decreases SEU cross-sections
  - Has no change in SEU cross-sections
- Angle analysis should be performed.
- SEU data obtained at angle should not be mixed with data obtained at normal. Use separate graphs.

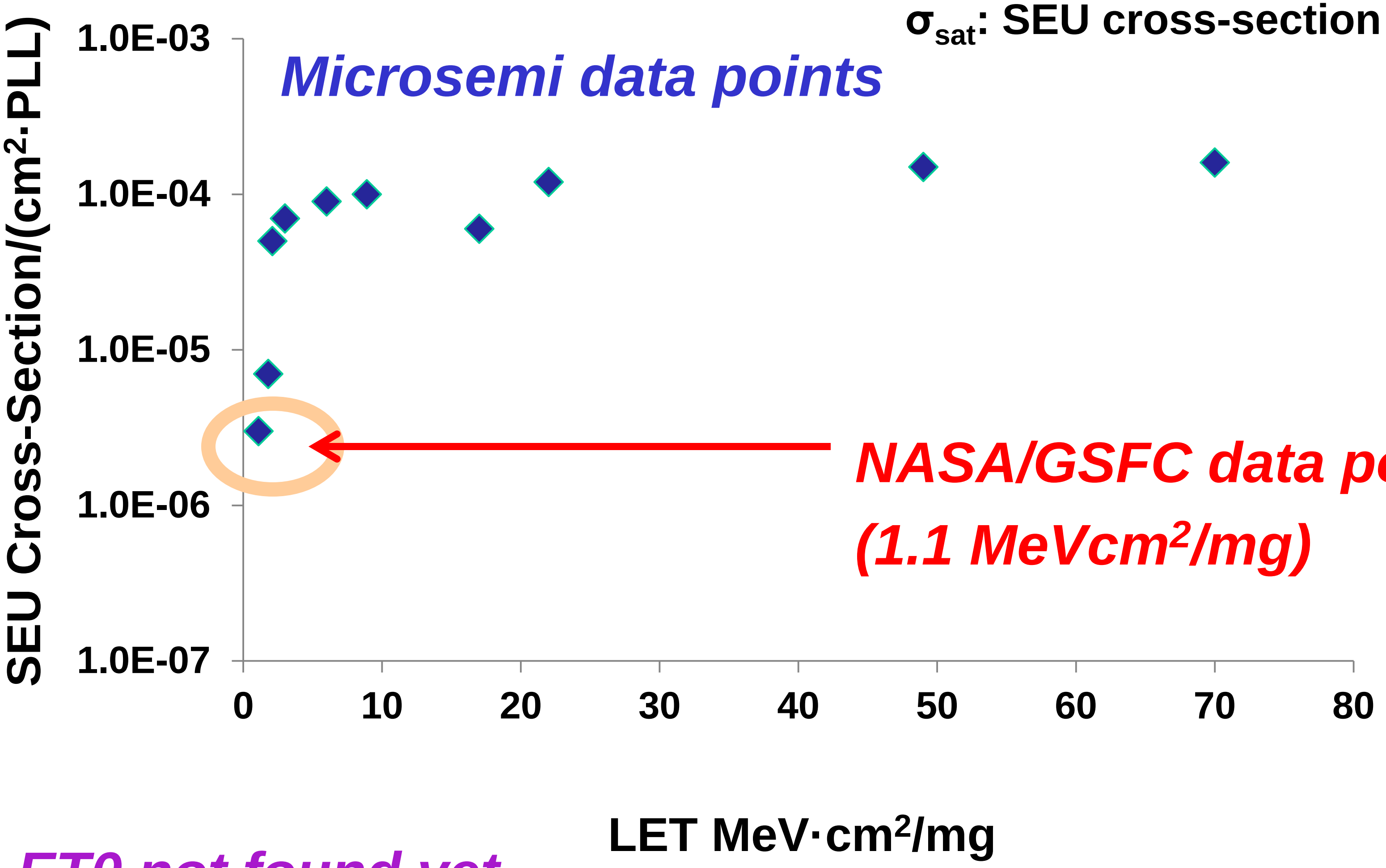


TMR PLL SEU Data

LET$_{sat}$: LET saturation

LET$_{TH}$: LET threshold

σ_{sat}: SEU cross-section saturation



Microsemi data points

NASA/GSFC data point (1.1 MeVcm^2/mg)

LET0 not found yet

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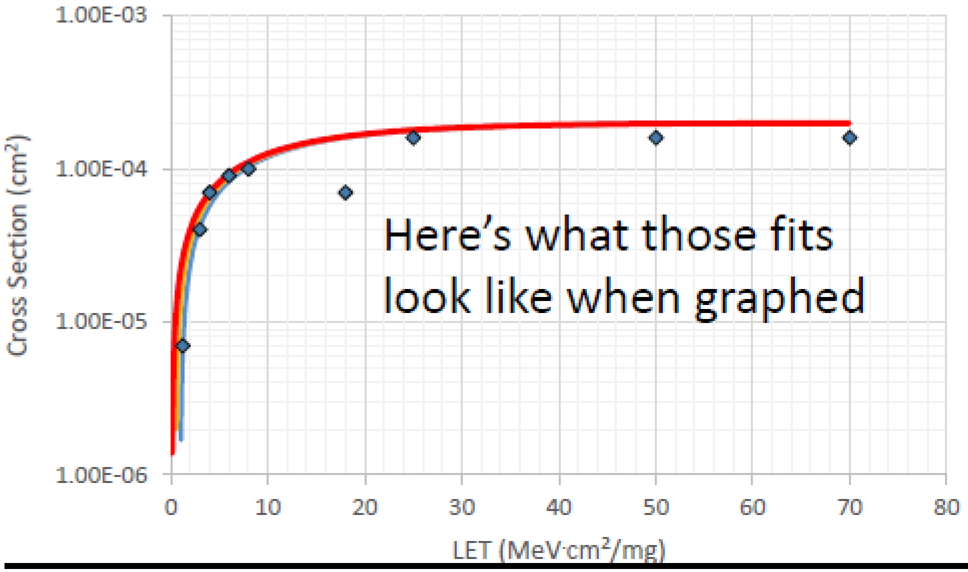
RTG4 TMR PLL SEU Data Analysis:

4 Parameter Weibull Fit and CREME96

L0 (MeV.cm2/mg)	W (MeV.cm2/mg)	S	A0 (cm2)	Rate (upsets/PLL/day)	Days between PLL upsets
1.1	10	.9	2e-4	4.8e-3	208
1	10	.9	2e-4	5.2e-3	192
.9	10	.9	2e-4	5.6e-3	179
.8	10	.9	2e-4	6e-3	167
.5	10	.9	2e-4	8e-3	125
.1	10	.9	2e-4	1.6e-2	62.5

Significant variance in rates depending on L_0.

Can saturated point values be trusted if obtained by angle?



Here's what those fits look like when graphed

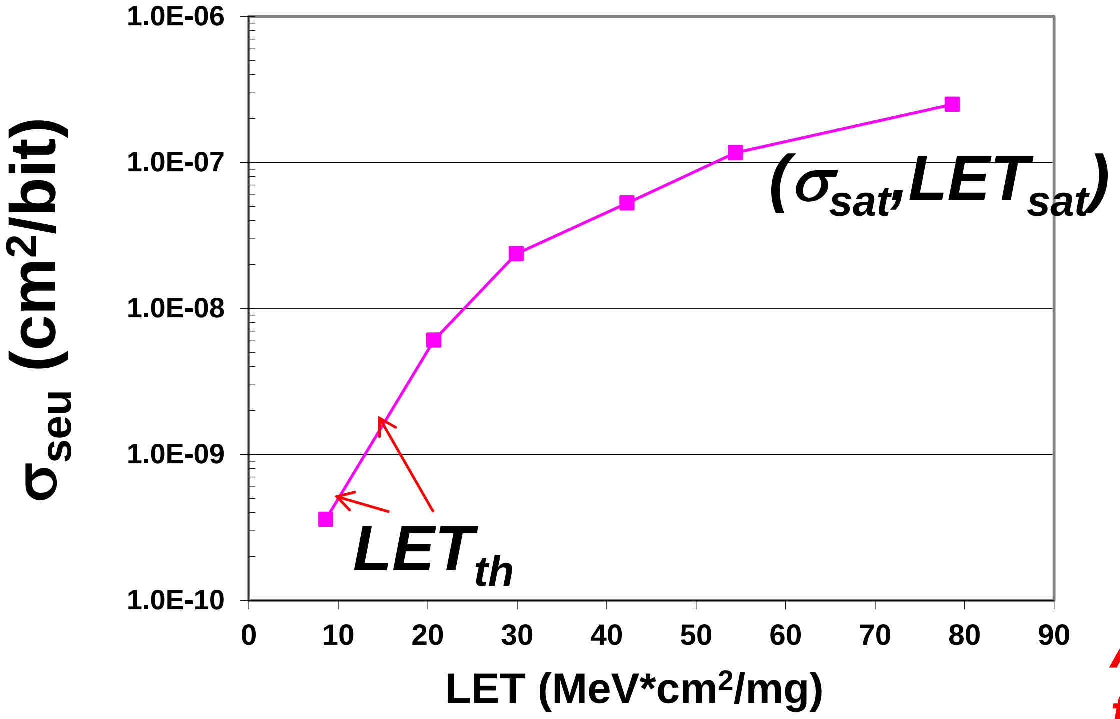
Petterson’s Rule of Thumb

$$\sigma_{seu} = \frac{\#errors}{fluence}$$

LET_{sat}: LET saturation

LET_{th}: LET threshold

σ_{sat}: SEU cross-section saturation



GEO Upset Rate:

$$\frac{dE}{dt} \approx \frac{400 * \sigma_{sat}}{LET_{th}^{\ 2}}$$

After Ed Petterson’s figure of merit.

Comparison of Error Prediction Methods

L_0 MeVcm^2/mg	W MeVcm^2/mg	S	A0 cm^2	Rate upsets/PLL/day	Days between PLL upsets (MTTF)	Petterson MTTF $LET_{th} = 4L_0$
1.1	10	.9	2e-4	4.8e-3	208	242
1	10	.9	2e-4	5.2e-3	192	200
.9	10	.9	2e-4	5.6e-3	179	162
.8	10	.9	2e-4	6.0e-3	167	128
.5	10	.9	2e-4	8.0e-3	125	50
.1	10	.9	2e-4	1.6e-3	62.5	2

Impact of TMR PLL MTTF

- **PLL control clocks (heart beat of a synchronous design).**
- **PLL glitch or unlock brings down the circuit.**
- **Generally systems have several PLLs. A system with 5 PLLs with a MTTF = 200 day/PLL-upset will have a system MTTF = 40 days/PLL-upset.**
- **This can be problematic for critical applications.**

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