A method of space radiation environment reliability prediction

Qunyong Wang, Dongmei Chen, Hua Bai, PhD
Beijing San-talking Testing Engineering Academy Co., Ltd. (STEA)

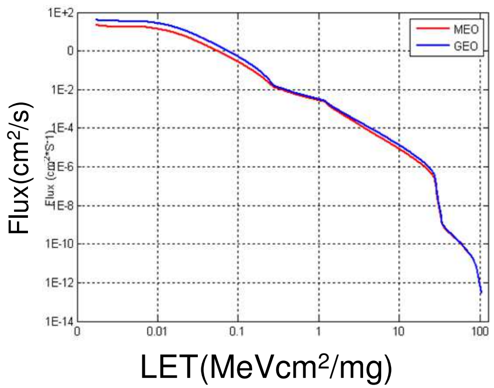
STEA
聖濤平

Overview and outline

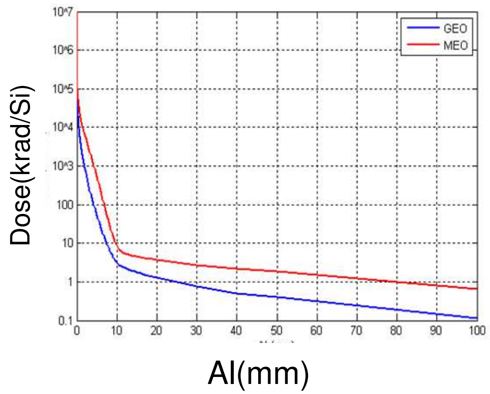
- Background and introduction
- Space radiation effects
- Basic model
- Prediction method
- Case study
- Summary and Conclusion

Background and introduction

- Space radiation environment is an important failure causing factor in space vehicles.
- Traditional reliability prediction method did not include the space radiation environment reliability.MIL-HDBK-217, No?   FIDES, No?
- It's the time to set up a method of space radiation environment reliability prediction.



- GEO/MEO SEE LET



- GEO/MEO TID

Space radiation environment effects

- Main failure modes

  Single Event Effect (SEE)

  Total Ionizing Dose (TID)

  Displacement Damage (DD)

- Radiation sensitive devices

  CPU, FPGA, SRAM, DC-DC, CCD , etc.

Space radiation environment effects

- SEE —instantiate effects,11 effects
- TID,DD—accumulated effects,parameter drift or functional failure

No.	Effects	Acronyms	Features
1	Single Event Upset	SEU	Non-destructive
2	Single Event Transient	SET	
3	Multiple-cell upset	MCU	
4	Single event functional interrupt	SEFI	
5	Single Event Disturb	SED	
6	Single Event Hard Error	SEHE	
7	Single Eevent Latch-up	SEL	Destructive
8	Single Event Burnout	SEB	
9	Single Event Gate Rupture	SEGR	
10	Single Event Dielectric Rupture	SEDR	
11	Single Event Snapback	SESB	

Space radiation environment reliability

Basic Model

- The failure rate induced by space radiation environment is the sum of 3 independent failure rates of SEE, TID and DD.

$$\lambda_{space} = \lambda_{TID} + \lambda_{DD} + \lambda_{SEE}$$

Failure physics and test support

Space radiation environment reliability

Basic Model

- Embedded into the traditional reliability prediction models based on stress-physical failures, e.g. FIDES model

$$\lambda = \lambda_{physical} \times \Pi_{PM} \times \Pi_{\Pr ocess}$$

FIDES model

Focus

$$\lambda_{physical} = \lambda_{NOspace} + \lambda_{space}$$

Related to the processes of quality control, manufacturing and usage of component and equipment.

Failure physics and test support

SEE reliability prediction method

- SEE is an instantiate effect, only happens during power on time of the sensitive devices.

Power on working hours yearly

$$\lambda_{SEE} = \sum_{i}^{SEEtype} \left(\frac{Annual\_time_{SEEtype-i}}{8760} \lambda_{SEEtype-i} \right)$$

Calendar hours in a year

The ith SEE failure effects in 11 types.

SEE reliability prediction method

- SEE failure rate prediction method under radiation stresses.

Radiation stresses

Device Intrinsic characteristics on radiation resistance

$$\lambda_{SEEtype-i} = \int_0^{\infty}\int_{-1}^{1}\int_0^{2\pi} f(LET,\theta,\phi)\,\sigma_{SEEtype-i}(LET,\theta,\phi)\,d\phi\, d(\cos\theta)\, dLET$$

4-parameter-Weibull fit description

$$\sigma_{SEEtype-i}(LET) = \sigma_{sat}\left[1 - e^{-\left(\frac{LET-LET_{th}}{W}\right)^{S}}\right]$$

TID/DD reliability prediction method

- Sensitive devices TID/DD failure distribution—lognormal
- Intrinsic radiation resistance—failure distribution parameters

（μ,σ）

$$\mu = \frac{1}{n}\sum_{i=1}^{n} \ln(R_{TIDFAIL-i}), \qquad \sigma = \left(\frac{1}{n-1}\sum_{i=1}^{n} [\ln(R_{TIDFAIL-i}) - \mu]^2 \right)^{1/2}$$

$R_{TIDFAIL-i}$ ： the failed TID for the i^{th} sample (unit: rad)

Radiation stresses

Device Intrinsic characteristics on radiation resistance

$$S_{TID}(T) = 1 - \Phi\left[\frac{\ln(R_{specTID}(T)) - \mu}{\sigma} \right]$$

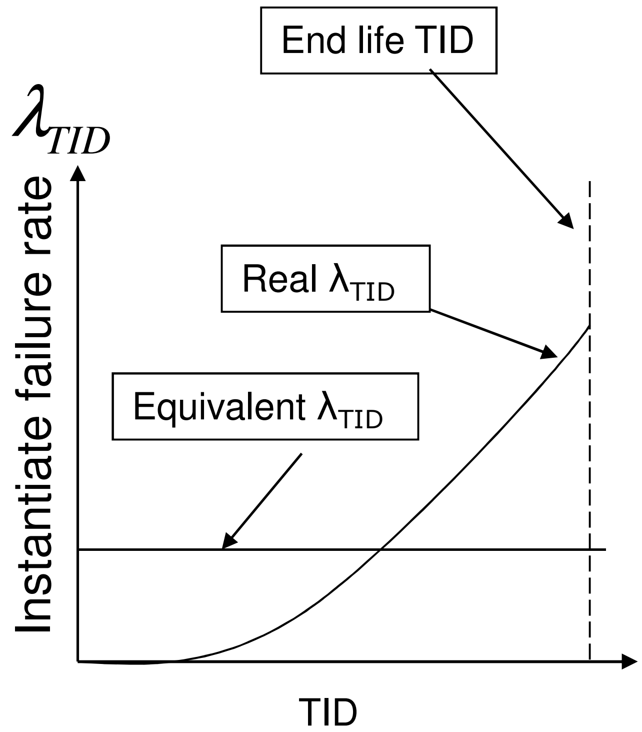
TID/DD reliability prediction method

- For simple use in engineering, define an equivalent constant failure rate upon the equal end life survival probability.

$$\lambda_{TID} = -\frac{1}{T}\ln\left(S_{TID}(T)\right)$$

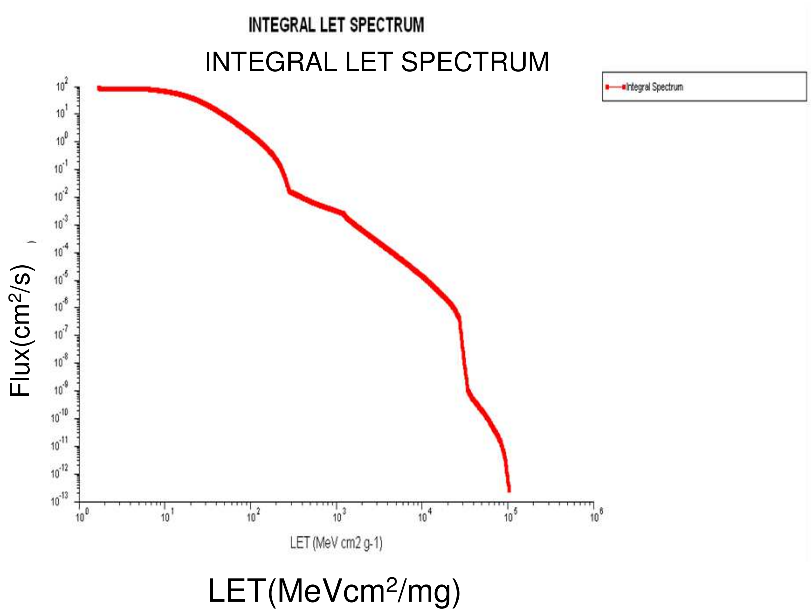
$$= -\frac{1}{T}\ln\left\{1 - \Phi\left[\frac{\ln(R_{specTID}(T)) - \mu}{\sigma}\right]\right\}$$

Note：Equivalent only within the design life T.

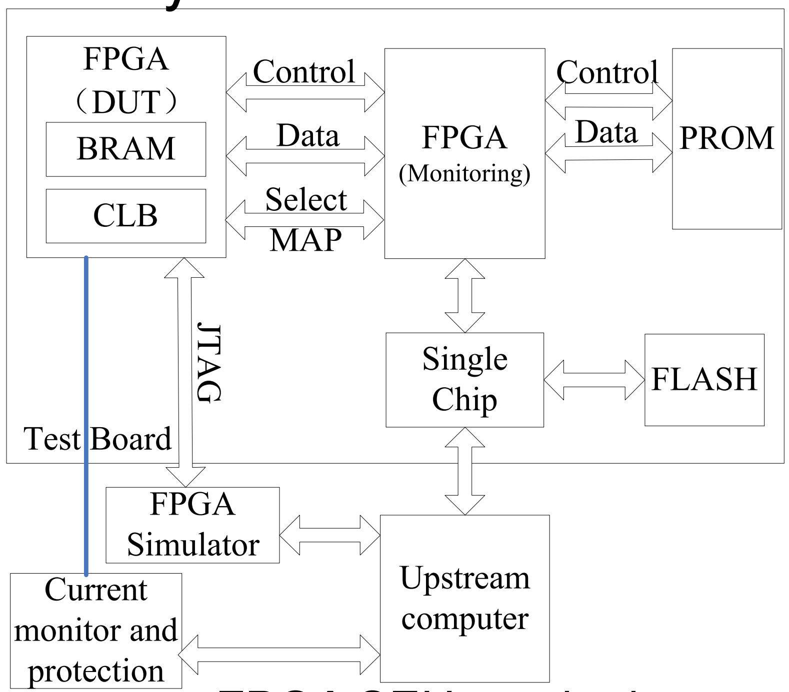


Case study

- Assume satellite to be launched in 2015，GEO，T=12 Y.
- Mission space radiation stresses: TID 69.8krad, LET spectrum in figure 1.
- Key sensitive device: SRAM-FPGA，TID/SEU sensitive
- Ground test: ^{60}Co TID, LINAC Heavy ion SEU



GEO LET



FPGA SEU monitoring system

Case study

- λ_{TID} prediction

FPGA failed TID test data

No.	$R_{TIDFAIL}$ krad（Si）
1	310
2	180
3	170
4	210
5	210
6	170
7	507
8	210
9	210
10	250
11	170

⇒

μ=12.3
σ=0.33

⇓

$$\lambda_{TID} = -\frac{1}{8760\times 12}\ln\left\{1-\Phi\left[\frac{\ln(69800)-12.3}{0.33}\right]\right\}$$

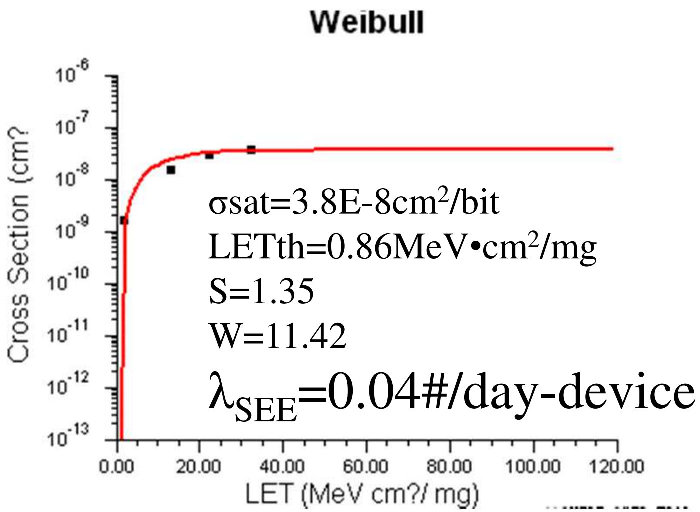
$$= 2.5\times 10^{-9} h^{-1}$$

Case study

- λ_{SEE} prediction

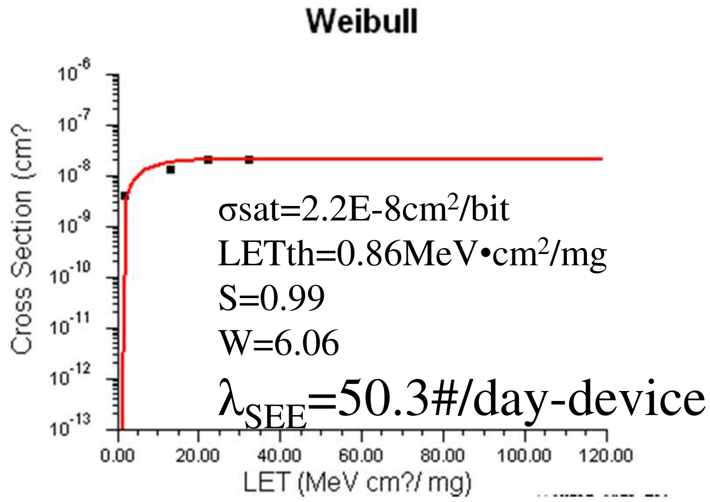
BRAM（8192bits）SEE test data

Heavy ion	LET MeVcm²/mg	Flences cm⁻²	SEU #	σ cm²/device
C	1.73	3.40E5	5	1.47E-5
Cl	13	1.90E5	25	1.32E-4
Ti	22.2	2.55E5	65	2.55E-4
Cu	32.4	1.09E5	32	3.13E-4



CLB （7543040bits）SEE test data

Heavy ion	LET MeVcm²/mg	Flences cm⁻²	SEU #	σ cm²/device
C	1.73	1.01E6	33282	3.295E-2
Cl	13	5.50E4	5841	1.062E-1
Ti	22.2	2.34E5	38123	1.629E-1
Cu	32.4	1.89E5	31767	1.681E-1



Summary

- Based on space radiation failure mechanism and statistical characteristics, a method of space radiation environment reliability prediction is setup upon failure physics, which expands the application domain of reliability prediction.

- To be applied on reliability design for future space vehicles.