Radiation Damage of electronic components to be used in a space experiment

Presented by:

Mauro Menichelli

La Biodola, 18th May 2002

Perugia
INFN
Istituto Nazionale di Fisica Nucleare

Summary

- Radiations in space
- Radiation damage on discrete components
- The ESA test procedure
- Total dose test results
- Single event effects
- Single event test results

Radiation damage effects

- Total dose effects
- Single event effects (SEE)
  - The single event latchup (SEL)
  - The Single event transient/upset (SET/SEU)
  - Other effects (SEGR or SHE)

Radiations in space

- Cosmic rays
- Solar flares
- Trapped Secondary particles
- Solar wind

Cosmic rays compositions

- 83% Protons
- 13% Helium nuclei
- 1% nuclei Z>2
- 3% electrons

Cosmic ray spectum

- It ranges from tens of MeV to more than 100 EeV
- Above few GeV up to 1 PeV follows the law:

$$\Phi = k\, E^{-2.7}$$

- Isotropic outside the earth magnetic field
- Influenced from the terrestrial magnetic field and the solar activity

Secondary component and trapped component

- Secondary component produced from the interaction of primary cosmic rays in high atmosphere (negligible above 1000 km).
- Trapped component made by Protons and electrons trapped in Van Allen belts or below
- At low orbits they are relevant in the south atlantic anomalies

Solar, planetary and anomalous component

- Solar component: Higher energy component of solar wind it extends up to 20 MeV
- Planetary component: electrons emitted from neutron decay on Jupiter
- Anomalous component: Helium, Oxigen and Nitrogen from interstellar da gas accellerated from the interaction with solar wind

Solar flares

- Protons, electrons and ions
- Emitted in high solar activity periods

Testing Procedures

ESA Procedures

- ESA/SSC 22900 total dose
- ESA/SSC 25100 single event effects

MIL Procedures

- 883 mtd 1019.4 total dose
- does not exist an equivalent procedure for SEE with ions but 883 mtd 1020.1 deals with latchup with x−rays or electrons and 883 mtd 1021.2 deals with upsets using the same sources

Total dose units

- Total dose measuring unit:
  - 1 Gy = 1 J/kg
  - 1 rad = 100 erg/g = 0.01 Gy

Types of radiation damages

- Displacements
  - $\tau - \tau_0 = K_\tau \phi$
  - Radiation damage on JFET and diodes
- Ionization
  - Damage on MOSFET and also BJT for oxide charge

Radiation damage on diodes and JFETs

- Diodes have mostly displacement damage because both direct and reverse current depends on charge carriers lifetime but are visible only at high doses.
- JFETs are unipolar majority carriers devices without oxides the damage mostly due to displacement and it is generally negligible below 1 Mrad.

Radiation damage on BJT

- Gain degradation due to recombination of carriers in charged oxide and displacement damage
- Increase of saturation V_{CE} (ddisplacement damage)
- I_{CBO} increase due to oxide ionization

Radiation damage on MOSFETs

- Damage due to charge trapping in the oxide for ionization

Procedure ESA/SSC 22900 for total dose tests

- Purposes and terminology
- Test equipements
- Evaluation test procedure
- Lot testing procedure

Radiation source

- Co60 gamma ray source with dosimetry precision better than 5% and uniformity of dose on DUT better than 10%
- Electron beam with energy deposition in the die from 1 to 3 MeV with uniformity better than 10%
- The ambient temperature of the irradiation laboratory should be 20 +/− 10 C.

Irradiation plan

- Determination of the dose of interest from simulation of the space enviroment (CREME)
- Dose rate evaluation
- Determination of the parameters that should be measured during the test.
- The irradiation is done in three steps (but they can be even more than 3) at 1/3, 1, e 3 times the dose of interest with intermedite measurement of the parameters. The stops can last 2 hours maximum.

Dose and dose rate

- Standard doses are:
  - 3krad − M
  - 10krad − D
  - 20krad − E
  - 50krad − F
  - 100krad − R
  - 1Mrad − H
- Dose rates are:
  - Standard rate from 3.6 to 36 krad/h (1−10 rad/s)
  - Low rate from 36 to 360 rad/h (0.01 a 0.1 rad/s)
- The irradiation process lasts 96 hours maximum.

Additional requirements

- During the irradiation the component should be under bias (even if may be non operational).
- If the component is moved from the irradiation site the pins should be short−circuited.

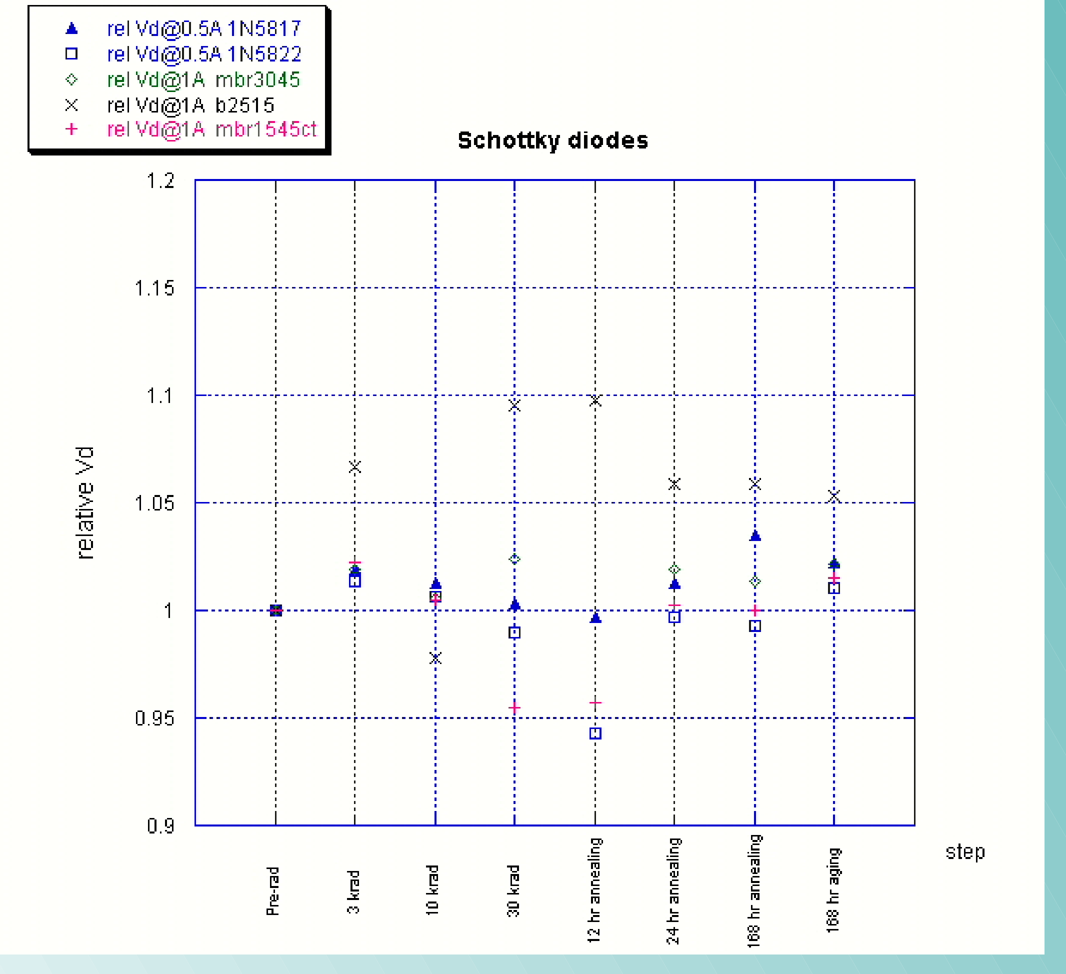
Post–irradiation measurements

- In order to compensate dose rate effects
  - After the irradiation the component is kept 168 hours (1 week)under bias at room temperature (25 C) (annealing) measuring the parametrs of interest after 12, 24 and 168 hours.
  - After the annealing the component is kept 168 hours (1 week) under bias at 100 C (aging) and then the parameters of interest are again measured .

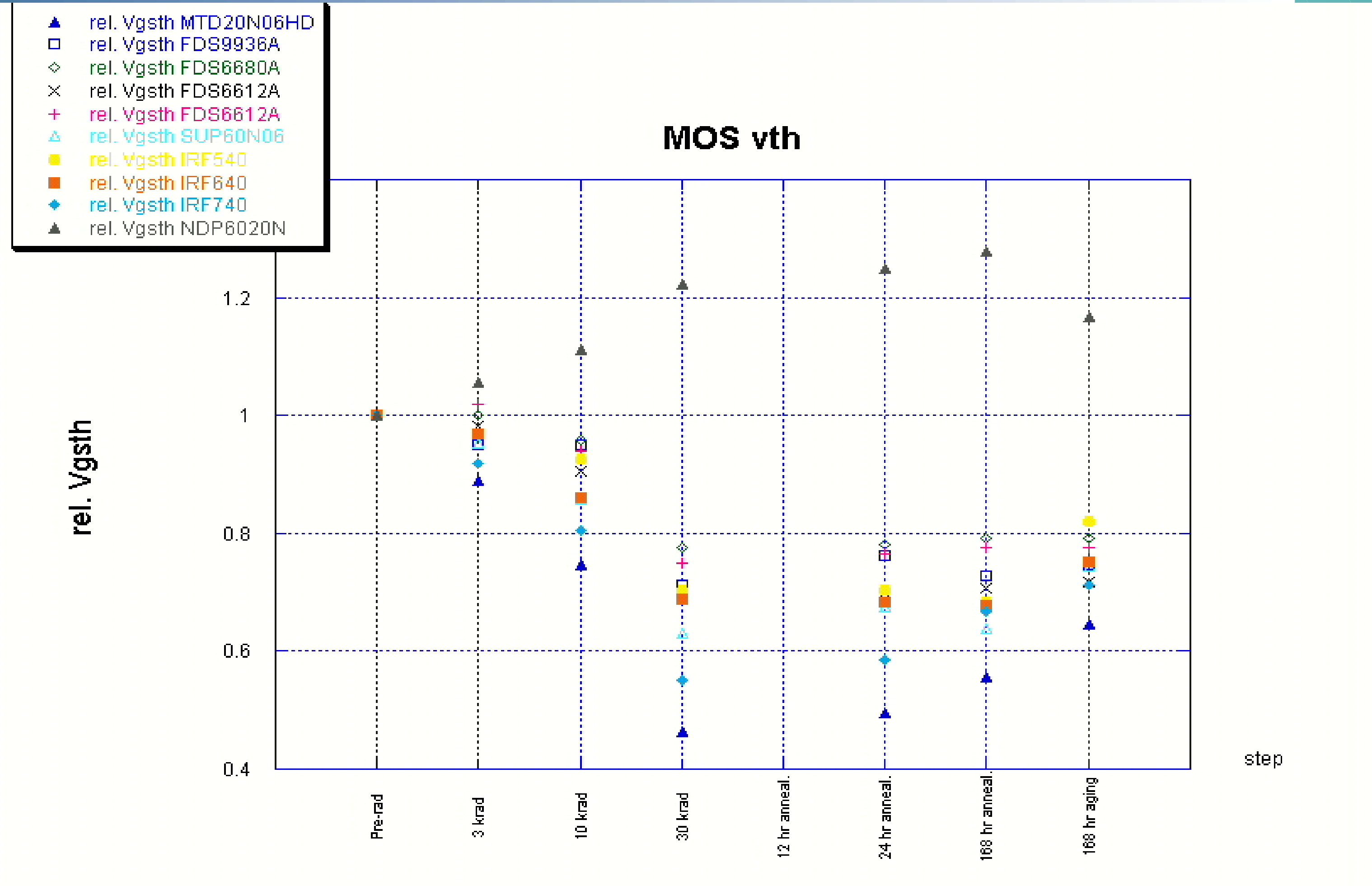
Lot testing

- Random selection of 11 components from the same lot.
- 10 undergo irradiation with the same procedure described for evaluation testing the other is kept as a reference.
- All irradiation measurement are done according the described procedure for evaluation testing exept that the annealing lasts only 24 hours.

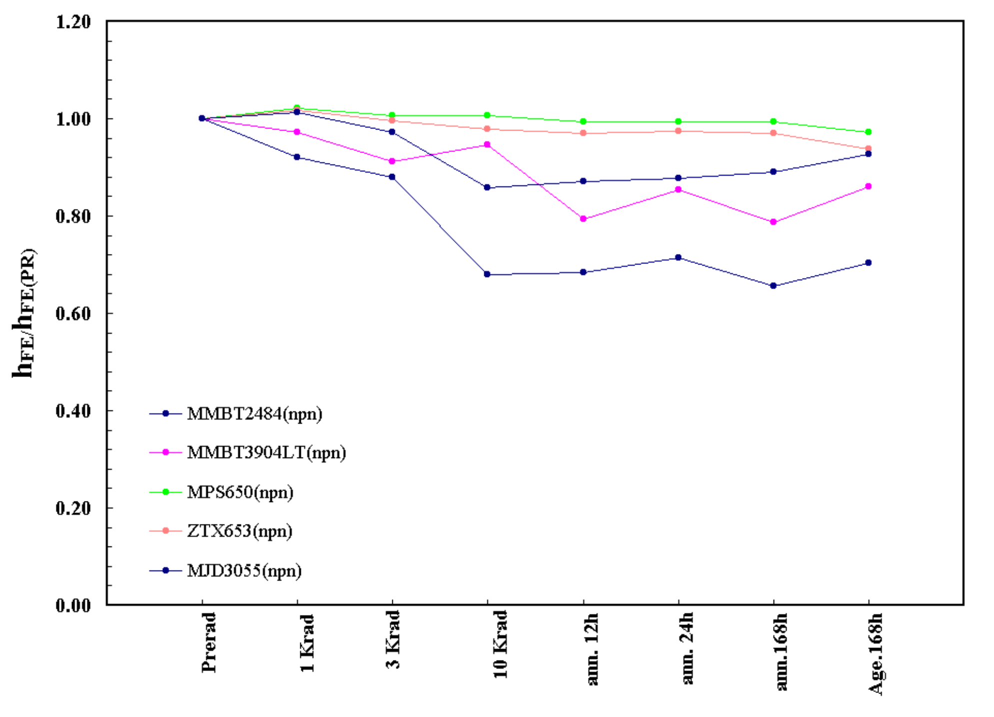
Forward drop on diodes



Threshold shift on MOSFETs



Gain variation on BJTs



The SEL

- Due to charge injection in the parasite BJT structure on MOSFETs.
- The effect is an overcurrent that may destroy the component

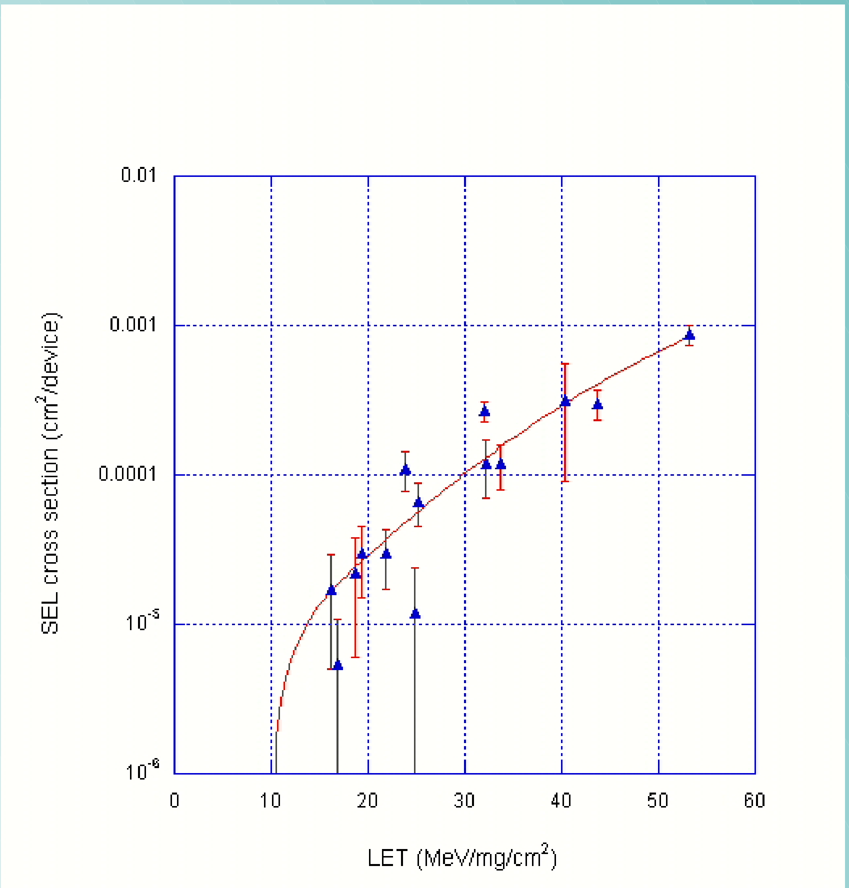
SET/SEU

- SET (Single Event Transient) is generated by a transient current spike due to an ion crossing the device.
- A SET in critical places of the circuit may become a SEU (Single Event Upset) i.e. bit−flip.

Relevant units and definitions

- LET linear energy tranfer
  - $MeV/mg/cm^2$
  - effective LET
- Flux $ions/cm^2$ /s and integrated Flux $ions/cm^2$
- Cross sections
  - Number of upsets or latchups/(integrated flux)

SEL cross section versus LET for ADSP 2187L



SEU cross section versus LET for ADSP 2187L