Electronic Radiation Hardening
- Technology Demonstration Activities (TDAs)

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Outline

• Radiation effects and technology hardening
  – TID
  – TNID, SEE

• Technology Demonstration Activities
  – T222-019QC – Critical components for power systems
  – T222-020QC – Radiation characterisation of Laplace critical RH optocouplers, sensors and detectors
  – T222-016QC – Radiation Hard memory; Radiation testing of candidate memory devices for Laplace Mission
Specific constraints of the JGO radiation environment

JGO radiation environment

- Trapped Particles
  - electrons
  - protons
  - heavy ions
- Transient Particles
  - solar event protons and heavy ions
  - galactic cosmic rays

Radiation effects at the device level

- Total dose effects
- Displacement Damage effects
- Single Event Effects (SEE)
Charge buildup in field oxides can cause large increase of the leakage current because of the lateral parasitic transistor.

CMOS technology 0.8um, LOCOS isolation

[Experiment, Simulation]

Drain current (A) vs. Gate voltage (V)

50 krad, 40 krad, 30 krad, 20 krad, 10 krad

[Reference: Ferlet HDR05]
Technology hardening is possible, for example by doping under the field oxide; but it is often a trade-off against electrical performances.

[Ferlet HDR05]

**Diagram Description**

- **100 krad(SiO₂) – 10keV X-ray**
- **Drain current (A/µm)** vs **Gate voltage (V)**
- **OFF-state drain current (A)** vs **Maximum doping (cm⁻³)**
- **Non-hardened reference**
- **Doping optimization**
- **Source**
- **Gate**
- **Drain**
- **P+ retrograde Field implants**

**Graph Details**

- **Drain current (A/µm)** on a logarithmic scale from $10^{-13}$ to $10^{-3}$
- **Gate voltage (V)** from -3 to 3
- **OFF-state drain current (A)** from $10^{-4}$ to $10^{-12}$
- **Maximum doping (cm⁻³)** from $10^{16}$ to $10^{18}$

**Legend**

- **100 krad**
- **30 krad**
- **50 krad**

**Text**

- **Courant en mode bloqué (A)**
- **Dopage maximum NA max (cm⁻³)**
- **Drain**
- **Tension de grille (V)**
- **référence non durcie**
- **implantations rétrogrades**
- **Gate voltage (V)**
- **Drain current (A/µm)**
- **Doping**
- **Non-hardened reference**
- **optimization**
Another source of radiation-induced leakage current is the parasitic “inter-device” transistor.

Inter-device leakage is efficiently mitigated with P+ guard ring, but at the expense of area penalty.
Hardness by design methodology: rad-tolerant design rules for IC design

[Nowlin, 2005]
Area Comparison – 2NAND Logic Gate

1x Area

Edgeless Transistor

Guard Bands

1.7x Area

Widened Busses

2.3x Area

Std. Design 0.35-\(\mu\)m Comm.

Rad-Hard-By-Design 0.35-\(\mu\)m Comm.

Std. Design 0.50-\(\mu\)m 1 Gen Behind

[R.C. Lacoe et. al., TNS Dec. 2000 ]
Highly scaled CMOS technologies, with standard design, are less sensitive to TID

Compilation from [Lacoe03, Anel97, Kerwin98, Shaneyfelt98, Brady99, Lacoe99, Lacoe00, Lacoe01, Nowlin04]
However, real systems use a wide variety of IC technology generations, for which TID hardening is not granted.

Compilation from Radiation Effect data workshops between 2002 and 2004

[Dodd09]
Significant variation is observed on the TID sensitivity, even for same “date code” parts.

8-Gbits NAND-Flash, Samsung & ST

Biased vs unbiased tests: 10 + 8 samples

Example of COTS mass memory

[Schmidt, IDA, 2008] under ESA contract

EJSM Instrument Workshop, 19 January 2010, ESA-ESTEC
TID in power MOSFET

[Shaneyfelt et. al., TNS 2008]

EJSM Instrument Workshop, 19 January 2010, ESA-ESTEC
Optoelectronics is highly sensitive to TNID - degradation of the minority carrier lifetime

4N49 optocoupler: relative CTR with respect to fluence

TID / TNID Mitigation

• Reduce the dose levels
  – Improve the accuracy of the dose level calculation
  – Change the electronic board, electronic box layout
  – Add Box and/or Spot shielding

• Increase the failure level
  – Tolerant library => DARE library
  – Tolerant designs (cold redundancies, etc.)
  – Test of the flight lot, with significant sampling
  – Test in the application conditions
    • Duty cycle (biased-unbiased devices)
    • Temperature
  – Test at low dose rate (CMOS only)
  – Relax the functional requirements

[C. Poivey, RADECS 2003]
SEE characterization

Samsung 1Gbits DDR1 SDRAM

8-Gbits NAND-Flash, Samsung

SEU-MBU-SEFI-SEL:
Effect of die revision: $x10^2$ SEU rate
Lot-to-lot variations

[Ladbury 2006]

SEFI:
• Rows, columns, blocks are in error;
• Need reset or power cycling
• Mitigated by decreasing the refresh time
• Must be taken into account by the system

[Hagen Schmidt, IDA, 2008]

EJSM Instrument Workshop, 19 January 2010, ESA-ESTEC
End of Life reliability: stuck bits

Large part to part variations

[Edmonds 2001]

Micro-dose or -displacement damage

[Edmonds 2008]
SEE Mitigation

• Devices sensitive to destructive failures **must be discarded**
  – SEGR / SEB in Power MOS
  – Latch-up in CMOS

• Implies careful design and/or part selection
  – ASICs designed with a rad-tol or rad-hard technology and/or library
    ➢ DARE Library
  – SEE rad-hard parts whenever possible

Test of the flight lot with significant sampling
Technology Demonstration Activities (TDAs)

• T222-019QC – Critical components for power systems
  ➢ Christian Poivey

• T222-020QC – Radiation characterisation of Laplace critical RH optocouplers, sensors and detectors
  ➢ Marc Poisat

• T222-016QC – Radiation Hard memory; Radiation testing of candidate memory devices for Laplace Mission
  ➢ Fredrick Sturesson
Survey of critical components for 150 krad power systems

- Project scheduling
  - Duration 18 months
  - KO meeting in November 2009

- Components for Power systems
  - Power DC/DC converters 10-30W
  - PCDU – Power control and distribution – 500-1000W

- Radiation tests
  - Total ionizing dose: 150 krad(Si)
  - Displacement damage: about $10^{11}$ cm$^{-2}$ equivalent 10 MeV protons
Survey of critical components for 150krad power systems (2)

- Surveyed functions
  - Power MOSFETs
  - MOSFET drivers
  - Operational amplifiers
  - Voltage comparators
  - Optocouplers
  - Discrete bipolar transistors
  - Schottky diodes
  - Voltage references
  - Analog multiplexers
  - CMOS logic
  - Pulse Width Modulators

- Pre-selection of Rad-hard parts whenever possible
- Bipolar-based parts will be tested for ELDRS (Enhanced Low Dose Rate Sensitivity)
- Combined effects Co60 and protons (TID-TNID)
- Selected parts shall not be sensitive to destructive events
T222-020QC
Radiation characterization of optocouplers, sensors and detectors

• Project scheduling
  – KO meeting expected Q2 2010,
  – Project duration 18 months

• Tested Components:
  – Optocouplers and APSs (Active Pixel Sensors)
  – Selected from rad-tol or rad-hard devices
  – Complete the existing radiation data

• Radiation tests: TID, TNID and SEE
  – Total ionizing dose: 150 krad(Si)
  – Displacement damage: protons (about $10^{11}$ cm$^{-2}$ eq. 10MeV) and neutrons
  – Combined TID and DD experiments
  – SEE: protons 100-175-250MeV
T222-020QC
Radiation hard memory; radiation testing of candidate memory devices for Laplace mission

• Project scheduling
  – KO meeting expected Q2-Q3 2010,
  – Project duration 36 months

• Selection of memories
  – Flash Memories
  – SDR SDRAM memories
  – DDR2 (or DDR3) memories
  – DDR2 memory interface devices
  – Phase Change Memory (PRAM), FeRAM, MRAM, any other memory type

• Radiation tests: TID, TNID and SEE
  – Total ionizing dose: 150 krad(Si)
  – SEE: protons and heavy ions
    • Latch-up, SEFIs