SPACE TRANSPORTATION

MEMSRAD Radiation Testing Guidelines

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MEMSRAD
Radiation Testing Guidelines for MEMS

Outlines

- Introduction: Purpose of this work and methodology
- From space environment to ground level testing
- Radiation Testing Standards and guidelines
- Specificity of MEMS
- Information gained from testing 2 types of MEMS
- Conclusions

Introduction (1)
Project Team

Contract N°: 20293/06/NL/CP

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- **Technical Officer EADS-Astrium ST : C. OUDEA**

- **Members of Consortium**
  - **EADS - Astrium Space Transportation : Prime**
  - **Sub Contractors:**
    - **Astrium Sat (GmbH)**
    - **EADS- IW (Innovative Works), Ottobrun (Ge)**
    - **Thales Alenia Space, Toulouse (Fr)**
    - **Infoduc (Fr)**

Introduction (2)

General

- Purpose of this work
  - Prepare guidelines for Radiation Testing of MEMS
  - Help to perform characterization of MEMS and obtain meaningful results.
  - Allow different labs to share and compare results obtained with a common testing procedure.
- Methodology
  - Analysis of existing Radiation Testing Guidelines and Methods
  - Identification and Classification of MEMS
  - Identify important points to adapt or modify the guidelines
    - a priori
    - after performing tests on MEMS

Consider other Testing Guidelines applied to MEMS:

- Reliability evaluation
- Specific testing methods related to the specific function

Introduction (3)

Statement:
To work correctly in space applications,
MEMS must be qualified
to Space Radiation Environment Specifications.

How?

Apply **as is** existing guidelines for electronic devices

Develop new guidelines

RadiationTesting Methods and guidelines
MIL-STD-883
ESA-ESCC
ASTM
JEDEC

Analysis and adaptation if necessary of existing guidelines

Reliability evaluation guidelines

MEMSRAD
New Guidelines

a priori : first release

After Testing of 2 Types of MEMS
2^{nd} Release

Space Environment and Ground Level Simulation (1)

Radiation:
Electrons, protons, Heavy ions

Energy Spectrum
Flux

Interaction codes, Spacecraft Structure (Shielding,…)

Total Ionizing Dose (TID) (rad, Gray)

Non Ionizing Energy Loss (NIEL)
(Equivalent Fluence)°

LET Spectrum

Mission
Orbit,Duration
Working Period

Environment Evaluation Codes , data base

Space Environment and Ground Level Simulation (2)

Specifications

Total Ionizing Dose (TID)
(rad, Gray)

Non Ionizing Energy Loss
(NIEL)
(Equivalent Fluence)°

LET Spectrum

Radiation Facilities?

Availability, Cost, Test Validity

➡ **Co^{60} γ Rays**, electrons, protons

➡ **Protons**, neutrons

➡ **Heavy Ions,** pulsed and focused Laser

How to Proceed?

Radiation Testing Standards and Guidelines

Radiation Tests

MUT
Sensor Inputs
Measurement Methods
Hardware

Radiation Facility
Dosimetry
Electronic Equilibrium
Focalisation
Shielding
Ion Range
Vacuum

Adapt Test Plan and Test Procedure to the limitations of the facility

Standards and Guidelines

- Content
  - Facilities:
    - Simulation of **effects**, not environment
    - Dosimetry
  - Test Plan: « What we want to do »
    - Number of devices, parameters, irradiation level (dose, fluence, ….),
    - Configuration under irradiation,
    - On line or remote measurements…
  - Test Procedures: How to realise the Test Plan
    - Establish **good engineering methods** (cabling, measurement,..)
    - Selection of components to be tested
    - Preparation of the samples
  - Test report: Allow to compare and reproduce experiment
    - What was tested?
    - How it was tested
    - What was obtained

Radiation Testing Guidelines: Facilities

TID

Co^{60}

Dose rate available
Dose uniformity
Dosimetry and calibration
Volume available for irradiation
Connectors, cabling,..

Protons

Energy
Beam current,
temporal structure
Beam area,
beam uniformity
Dosimetry
Collimators
……..

Heavy ions

LET values
HI Ranges*,
Energy (MeV/amu)
Flux range (minimum-maximum)
Vacuum chamber
(volume, orientation, connectors)
Time to change ion species

ESA Sponsored Facilities

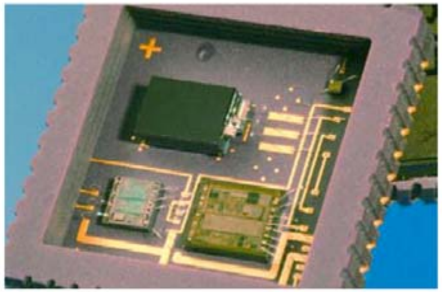
ESTEC Co^{60} source

UCL (Belgium)
PSI (Switzerland)

UCL (Belgium)
Jyvaskyla (Finland)

MEMS Under TEST: Choice criteria for MEMSRAD

- Stable production: Limited parameter dispersion
- Proven reliability:
  - able to withstand long duration tests
- Testing procedures (mechanical and electrical) already well known
- Two types:
  - one sensor type : acclerometer from Colibrys : MS8000
  - one actuator type: RF MEMS
    - From CEA/LETI



How many components are needed?

- Following numbers are recommanded numbers with the hypothesis of 2 dose rates in TID
- Stable components: 40
  - TID 20
  - SEE 5
  - DD 10
  - Ref and Spare: 5
- Pre-industrialised Components: 80
  - Pre screening to obtain homogeneous population
  - Evaluation of reliability

Radiation Testing Standards: TID

Standard	MIL-STD 883E **Method 1019**	ESA-ESCC 22900
Release date	1019.6 03/2003 1019.7 02/2006	Issue 2 08/ 2003
Radiation source	Co^{60}	Co^{60}
Uniformity Intensity	+-10% +-5%	+-5% +-5%
Dose rate (rad/s)		Window1: 1-10 Window2: 1 E-2 -1 E-1 Total irradiation time <96h
Dosimetry	ASTM Standards or other appropriate standards	ESCC21500, traceability to national standards

TID: On Line and Off-Line measurements

ON LINE

Advantages
Follow the degradation
Check correct bias, functionality
Drawback:
Restricted conditions
Limited parameters
Complexity of experiment
Cost of Development

REMOTE or OFF LINE

Advantages
Detailed characterization
Different bias and input conditions
Drawback:
Need removal from facility
Timing (annealing, rebound)
Discrete dose values

Mix ON-LINE and Remote measurement

Parameters to be measured and how to measure them

- Closely related to the function
  - (IMU, accelerometers, RF Mems, pressure sensors)
- In accordance to data sheet
- In accordance to standards
- MEMS are systems:
  - electrical and mechanical variables
  - Feedback
  - Global testing
- MEMS are **micro**-systems
  - Special apparatus and techniques (microscopy, interferometry,….)

MEMS 1: Accelerometer

- Pre-irradiation test in Laboratory
  - Zero offset
  - Linearity
  - Dynamic response as a function of frequency
  - Out of axis sensitivity
  - Maximum Range
- Apparatus needed:
  - Obtain the acceleration (rotating table ,..)
  - Vibration (frequency response)
  - Electronic apparatus (power supply, scopes, …..)
- On-line Monitoring:
  - Limited observations : Icc, Vout, Vtemp
  - Limited input conditions: +1g, 0g, -1g (use of gravity field)
  - Other input conditions: Development of specific hardware

MEMS 1 : Accelerometers:
On-line monitoring drawbacks and difficulties

- Observation: Avoid artefacts
  - Strong Increase in Icc supply current:
    - need Kelvin (4 wires) measurement to apply precise Power supply voltage

    (The output voltage value is closely related to power supply Voltage)
    - Sequential Automatic Measurements: During commutation, relays are opened and Power supply is reduced so that automatic reset may be induced (due to MEMS architecture and Microcontroller)
- Provide full input range to sensor:
  - Search of worst case conditions
  - Need a specific hardware (to be developed), logistics
- Huge quantity of information:
  - How to extract the useful parameters, control their validity and reduce data to useful information

RF MEMS: TID

On-Line monitoring drawbacks and difficulties

- Parameters to be measured
  - Activation levels, Hysteresis curve
  - S parameters: On and Off
  - Switching speed
- Apparatus: (Laboratory) Test Bench need specific development
  - Signal generators,
  - Network analysers
- On-Line monitoring:
  - Handling risks (ESD, charging, humidity)
  - Several devices: need commutation apparatus and sequential measurements (important development- reliability limitations)
  - Need to Anticipate degradation: increase the voltage dynamic of the generator
  - Evaluate the precision: sampling rate and dV/dt
  - Huge quantity of data: extract the threshold switching levels

TID: Hybrid MEMS what is the weakest part?

- Approach 1: separate irradiation of the parts
  - Use low energy X-Rays and masks with absorption adapted to X-Ray energy (Pb,..)
  - Irradiation of one part at a time
    - First evaluation: successive irradiations of the different parts to a given level: analysis of parameter variation
    - Detailed evaluation: Irradiation of only one part of a device at a given level, and construction of a model of degradation (summing contributions)

- Approach 2: Irradiate full devices
  - Extract specific parts (sensor, microcontroller, ASICs,..) and place them with good other parts, to identify their contributions

SEE Test limitations

- Heavy Ion Range
  - Package thickness: need to open package
  - Accelerometer: Sensor is too thick for high LET
  - Need to thin the sensor : influence on performance
- Limit the flux: Transient duration may be long
  - Avoid pile-up : errors in cross-section
  - Long test duration at low flux
- Influence of input conditions:
  - Difficult to simulate:
  - Need device tilting to use gravity field, but tilting modify effective LET and HI range
  - Or need a specific vibrating support working under vacuum

Displacement damage

- Accelerometer:
  - TID sensitivity was the most important
  - No observation of displacement damage
  - Neutrons should be used instead of protons (to limit ionisation damage)
- RF-MEMS
  - No observation of Displacement damage

Conclusion (1)

Improvement of guidelines

- Only Two types tested in MEMSRAD :
  - actuator, sensor
- Present Guidelines are oriented to radiation evaluation not to radiation qualification
- More MEMS types are to be tested, to gain more understanding of degradation mechanisms and to propose new test strategy.
- Guidelines should be updated with a period of 3 to 4 years

Conclusion (2)

- Most of existing radiation testing guidelines for microelectronics can be applied « as is »
  - Facilities,
  - Test plan, Test reports

➡ *MEMS designers and users (**MDU**) should contact Radiation Effects Testing Community (**RETC**)*

- Adaptations are necessary to take into account specificity of MEMS: mixed system of mechanical,(optical), electronic parameters
  - Measurement methods
  - Packaging limitations
  - Simulations of inputs to sensors
  - Worst case: Dose rate, bias, inputs, temperature
  - Heavy ions range limitations

➡ *Exchanges between MDU and RETC and Brain Storming is a must*

THANK YOU