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"Challenges ahead of a MEMS Qualification Standard Methodology"

8th ESA Round-Table on MNT for Space Applications
International Week on Micro and Nano Technologies for Space 2012
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Outline

- *Backdrop and status*
- *Benefits*
- *Challenges ahead*
  - *Strategy*
  - *Players*
  - *Knowledge*
  - *Testing*
  - *Equipment*
- *MEMS qualification standard methodologies*

MEMS standard qualification - Backdrop

“Testing, assembly,and reliability are the most important items for MEMS industrialization and account for the biggest part of their development time, but most researchers do not consider them an interesting research activity. Usually researchers prefer to focus their attention on design since they believe they can better express their creativity.”

Benedetto Vigna, VP of STMicroelectronics, MST News 2005

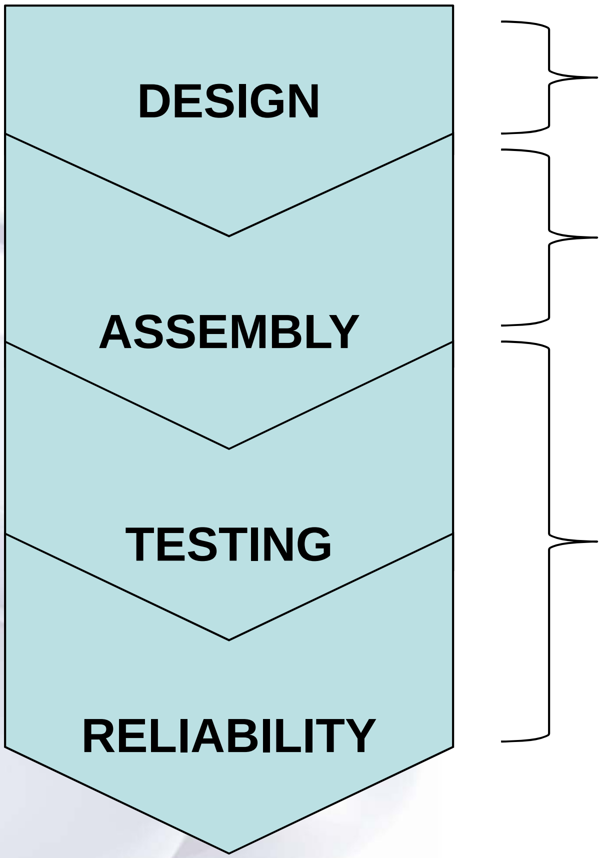
“Reliability testing and back-end handling protocols are commonly shared problems where standardization will improve productivity for the benefit of all.”

Tom Di Stefano CEO of CentipedeSystems, Chip Scale Review, 2012

“If we had common test techniques and standards for the data from the foundries, we could get more out of the simulation software.”

Alissa Fitzgerald, Founder,A.M.Fitzferald & Associates, SEMI, 2010

MEMS standard qualification : Status



Standardization

- *Adapted design SW*
- *Design methodologies derived from IC sectors*

- *IC manufacturing equipment*
- *IC manufacturing facilities*
- *Established suppliers*
- *Known materials*
- *Known manufacturing techniques*

- *High number of dissimilar devices*
- *Functional diversity (sensing/actuation method)*
- *Input and output parameters*
- *Fabrication Methods*
- *Materials*
- *Packaging diversity*
- *Different level of Integration (Dies/FE and BE electronics)*

MEMS standard qualification: Benefits

- *Leads to overall efficiency gains and cost reduction;*
- *Set best practices in the technological sector;*
- *Quality improvement for final users, performance and reliability wise;*
- *Fosters innovation through technological competition, yielding better and more reliable devices;*
- *Promote most capable players through compliance differentiation , thereby strengthening the technology and sector;*
- *Facilitates communication and comparative analysis;*
- *Decreases entry technical barriers to the MEMS sector;*

MEMS standard qualification: Challenges ahead

Area	Issue	Status
Strategy	- ***Medium and Long Term Strategy;*** - ***Funding;***	+
Players	- ***Networking*** *(MEMS Manufacturers, R&D centres, Test centres, Equipment Manufacturers);* - ***Testing and evaluation philosophies*** *of other segments, e.g. automotive;* - ***Consensus and commitment;***	+/-
Knowledge	- ***Common terminology and definitions*** - ***MEMS classification.*** *Can a simple but meaningful classification be achieved?* - ***Information exchange*** *(qualification protocols, failure detection techniques, reliability testing, failure mode characterization);*	-
Testing	- ***Standard evaluation procedures*** *(Which testing methods are relevant in a standard evaluation flow? Which are redundant or not critical?)* -***Test conditions;*** - ***Reliability models;*** - ***MEMS failure modes and failure rates;*** *(How to set pass/fail criteria?)* - ***Device and material characterization;*** *(which parameters are relevant?)* - ***Set of baseline parameters*** *for screening, evaluation and qualification.*	-
Equipment	- ***Standard test equipment*** *(tester, trays, carriers, ...)*	+

MEMS standard qualification : Strategy

Strategy

MNT Component Technology Board Dossier, MNT CTB Working Group

- -Status of micro-technologies, products and aplications;
- -MEMS devices analysis;
- -Concluded and ongoing activities;
- -Activities roadmap;
- -MEMS players targeting space applications;

Activities

2008/2010

AO/1-5490/07/NL/IA, "Procedures for MEMS Qualification"

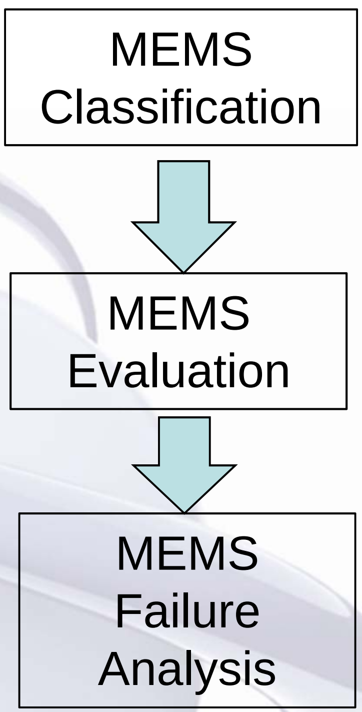
Objective: to develop an understanding of all aspects of the technology and its limitations in particular the tools necessary to procure, assess, screen and evaluate the technology in a time frame that is commensurate with potential ESA programme's needs.

2012/2014

"Validation and experimental verification of ESA MEMS qualification methodology"

Objective: Draft a ECSS Technical Memorandum addressing space MEMS qualification technology.

MEMS standard qualification : A standard approach



- Accepted MEMS classification methodology;
- Classificantion relevance by appropriate selection of classification criteria and group arrangement;
- Simplicity and easiness of understanding

- Standard MEMS screening, evaluation and qualification flows;
- General adequacy to MEMS technologies;
- Identification of specific evaluation needs per device technology;
- Test limits, lot size and pass/fail criteria;

- Standard failure analysis flows;
- Failure mode characterization;
- Failure mode models;
- Assocaition of failure types toinspection techniques

MEMS standard qualification: Classification Matrix

Moving	Functional	Working Principle	Suspending Element	Impact Motion	Active Element	Group
Yes	Optical	Electrostatic	Yes	Yes	Comb Drive/ Parallel Plate/ Thin Film/ Others	1
				No	Comb Drive/ Parallel Plate/ Thin Film/ Others	2
			No	Yes	Comb Drive/ Parallel Plate/ Thin Film/ Others	3
				No	Comb Drive/ Parallel Plate/ Thin Film/ Others	4
		Others	Yes	Yes	Comb Drive/ Parallel Plate/ Thin Film/ Others	5
				No	Comb Drive/ Parallel Plate/ Thin Film/ Others	6
			No	Yes	Comb Drive/ Parallel Plate/ Thin Film/ Others	7
				No	Comb Drive/ Parallel Plate/ Thin Film/ Others	8
	Non-Optical	Electrostatic	Yes	Yes	Comb Drive/ Parallel Plate/ Thin Film/ Others	9
				No	Comb Drive/ Parallel Plate/ Thin Film/ Others	10
			No	Yes	Comb Drive/ Parallel Plate/ Thin Film/ Others	11
				No	Comb Drive/ Parallel Plate/ Thin Film/ Others	12
		Others	Yes	Yes	Comb Drive/ Parallel Plate/ Thin Film/ Others	13
				No	Comb Drive/ Parallel Plate/ Thin Film/ Others	14
			No	Yes	Comb Drive/ Parallel Plate/ Thin Film/ Others	15
				No	Comb Drive/ Parallel Plate/ Thin Film/ Others	16
No	Optical	Electrostatic	Yes	-	Thin Film	17
				-	Others	
			No	-	Thin Film	18
				-	Others	
		Others	Yes	-	Thin Film	19
				-	Others	
			No	-	Thin Film	20
				-	Others	
	Non-Optical	Electrostatic	Yes	-	Thin Film	21
				-	Others	
			No	-	Thin Film	22
				-	Others	
		Others	Yes	-	Thin Film	23
				-	Others	
			No	-	Thin Film	24
				-	Others	

MEMS standard qualification: Classification Highlights

- 24 groups; 6 levels of classification (3 criteria based on the device functionality + 3 on physical features);
- 12 classification criteria considered
(Fabrication Method ,Working Principle (Sensing), Working Principle (Actuation) , Active Element Movement stop/ Material one side/ Material other side/Coating, Encapsulation/Internal Environment Limit, Visual Access, Moving, Impact Motion, Friction Motion, Suspended Element, Suspending Element)
- Proposed criteria and order minimizes the number of groups and maximizes the number of failure modes;
- Open system to new device and failure mode entries.

- Limited knowledge of failure modes and information on MEMS;
- Likely failure modes can evolve along with technological development;
- MEMS with low number of failure modes yield low classification usefulness. This problem is in line with micro devices arguably considered MEMS;
- No natural order. Compromise between grouping factor and devices with similar failure mode, i.e. devices failing into the same group share some failure modes but have others that can distinguish them;

MEMS standard qualification: Evaluation Flow

Pre-Stress Inspection

- Product Information
- Component Information
- Technical Key Features
- Main Manufacturing Processes
- Photographs (Sensor, Main Structures)
- Material List
- Assembly/Mounting Properties

- Functional Test
- Hermeticity
- Preconditioning
- ESD
- DDB
- PPIT
- PERA

Construction Analysis:
- Bond Strength Test
- Die Shear test
- Micro Sectioning
- Internal Water Vapour Content
- External VI
- Internal VI (SEM, X-Ray)

Stress Phase

Space Environmental

Thermal Vacuum
Depressurization
Out-gassing
Fine/Gross Leak

TID
Neutrons
Alpha
Protons
Flash X
Heavy Ions

HPOL/LPOL

Non-Space Environmental

HAST
PCT
THB

Mechanical Vibration
Mechanical Shock
Acoustic Vibration
Constant Acceleration

Temperature Cycling
Thermal Shock

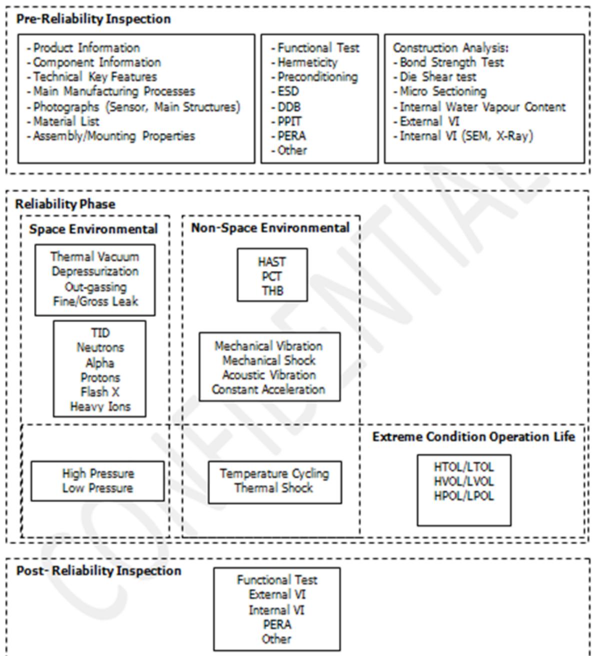
Extreme Condition Operation Life

HTOL/LTOL
HVOL/LVOL

Post-Reliability Inspection

Functional Test
External VI
Internal VI
PERA
Other

MEMS standard qualification: Evaluation Flow



Evaluation Flows

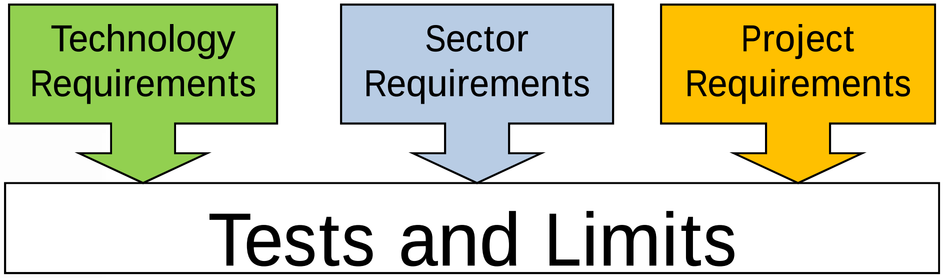
(Evaluation Flow1| EvalMethod_1| EvalMethod_2 |...|...|)
(Evaluation Flow2| EvalMethod_1| EvalMethod_3 |...|...|)
(Evaluation Flow3| EvalMethod_1| EvalMethod_4 |...|...|)
(Evaluation Flow4| EvalMethod_1| EvalMethod_4 |...|...|)
...

Standards&Conditions

(Type1| Standard_1|Test conditions 1|...|)
(Type2| Standard_2|Test conditions 2|...|)
(Type3| Standard_3|Test conditions 3|...|)
...

The final flow and applied standards are a derivation of a broader evaluation flow where parameters like complexity and usefullness are assessed.

MEMS standard qualification: Evaluation Flow (*Test/Test Conditions)*



Technology Requirements

➢Address the stresses type required to segregate fails closely related with the device operation and design features.

➢Provide evidence about the device performance throughout its lifetime by accelerating environmental and operational parameters such as temperature, pressure or voltage.

Sector Requirements

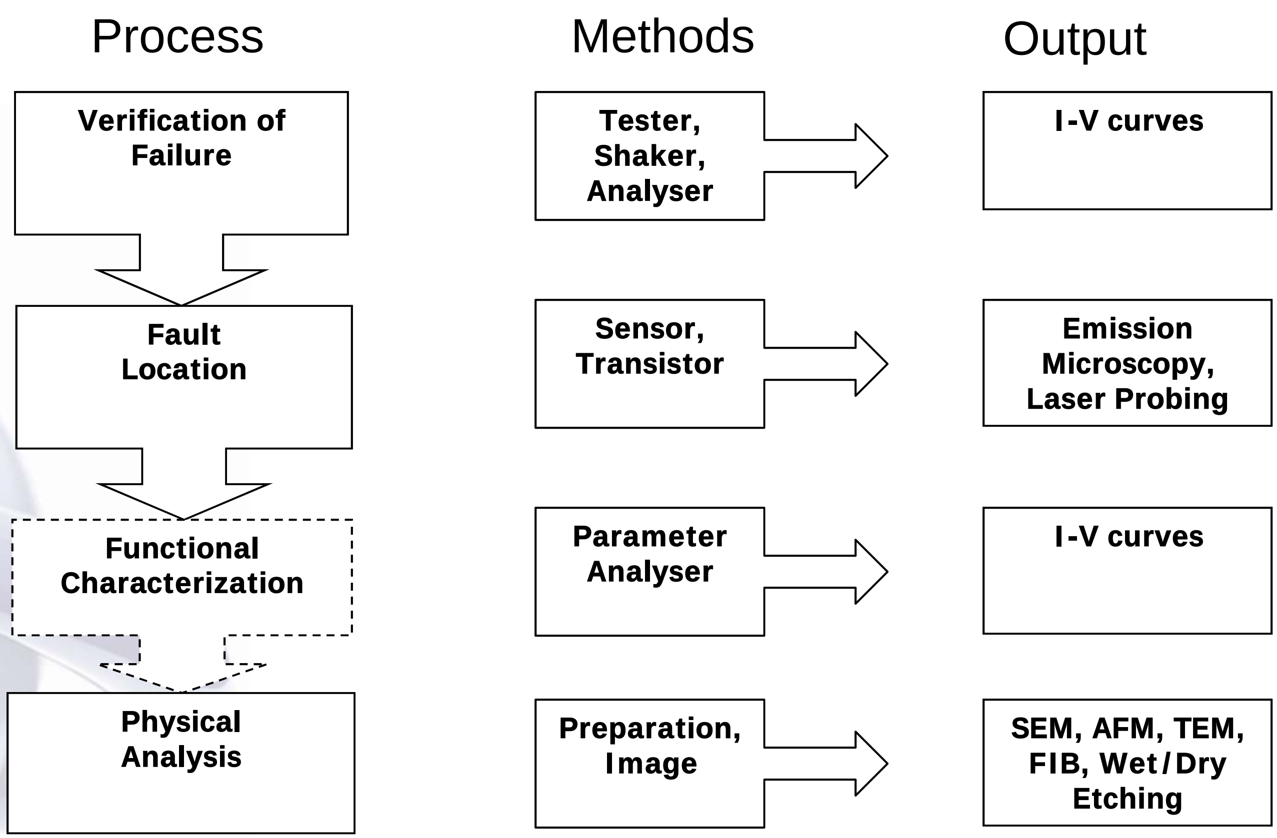
➢ Environment needs where the device is expected to operate. The space conditions dictate that issues such as hermeticity, thermal connectivity should be evaluated with appropriate limits and tests, e.g. out-gassing and depressurization.

Project Requirements

➢ Projects special needs. Each mission has its own targeted application and although the operational environment is partially common to every mission, specific operational needs may dictate specific limits and tests, e.g. the shielding against radiation or the typical operational temperature are simples examples may that led to additional tests with mission driven limits.

MEMS standard qualification: Failure Analysis Flow

Analysis Flow



MEMS standard qualification: Failure Analysis Flow Highlights

- **23 failure types listed and analysed**
(Function, Delamination, Elastic Deformation, Non Elastic Deformation, Crack, Fracture, Fatigue, Creep, Hermeticity, Rupture, Particles, Freeze, Stiction, Latch-up, Wear, Contact Damage, Conductor/ Isolator Void, Charging, Inter-Material Diffusion, Electro-Migration, Segregation, Micro Re-crystallization, Macro Re-crystallization, Corrosion)

- **19 groups of analysis techniques considered for the analysis flow, >45 techniques groups evaluated**
(Function, Visual, Visible noncontact, SEM, X-Ray, Other noncontact visual, SAM, can tip, Electrical, Pin-pin +pin-ground isolation, I-U –curve, Dynamic capacitance (admittance), Physical (Material analysis; special test), Chemical (Material analysis; special test), PERA, PIND, Any excitation AC response, AC excitation other response, Any excitation optical response)

- **33 evaluation methods analysed**
(Function, Stabilization Bake, Resistance to Soldering Heat, Solderability, Preconditioning, Burn-In, Temperature Cycling, Thermal Shock, High Temperature Operation Life, Low Temperature Operation Life, Temperature Humidity Bias, Highly Accelerated Stress Test, Pressure Cooker Test, Thermal Vacuum, Rapid Depressurization, Pin to Pin Isolation Test, Out-gassing, Fine and Gross Leak Test (Seal), Internal Water Vapour Content, Mechanical Shock, Mechanical Vibration,Acoustic Vibration, Constant Acceleration, Total Ionizing Dose, Neutron, Alpha, Protons Test, Flash X Test, Heavy Ions, Electrostatic Sensitivity Discharge, Dependent Dielectric Breakdown, Non Destructive Magnetic Test, Voltage Endurance Test, Residual Gas Analysis)

MEMS standard qualification

Moving	Functional	Working Principle	Suspending Element	Impact Motion	Group
Yes	Optical	Electrostatic	Yes	Yes	1
				No	2
			No	Yes	3
				No	4
		Others	Yes	Yes	5
				No	6
			No	Yes	7
				No	8
	Non-Optical	Electrostatic	Yes	Yes	9
				No	10
			No	Yes	11
				No	12
		Others	Yes	Yes	13
				No	14
			No	Yes	15
				No	16

Eval. Flow
1
2
3
4
1
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3
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1
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3
4
1
2
3
4

Moving	Functional	Working Principle	Suspending Element	Impact Motion	Group
No	Optical	Electrostatic	Yes	-	17
				-	
			No	-	18
				-	
		Others	Yes	-	19
				-	
			No	-	20
				-	
	Non-Optical	Electrostatic	Yes	-	21
				-	
			No	-	22
				-	
		Others	Yes	-	23
				-	
			No	-	24
				-	

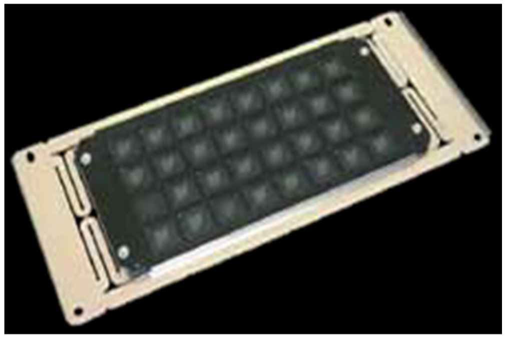
Eval. Flow
4
4
4
4
4
4
4
4

MEMS standard qualification: Test equipment

TnT FlexFrame™Tray

-Trays can be made to hold virtually any type of MEMS device to test pressure sensors, gas sensors, gyros, accelerometers, magnetometers, oscillators, microphones, cameras, switches, displays…

- Devices may be packaged in DIP, QFP,QFN, TSOP, BGA, CSP, WLP, flip-chip,or bare dice.



by Centipede Systems

Thermal test equipment

-Programmability of the system allows any arbitrary set of thermal stress profiles for qualification

-Control of temperature, gas and pressure within the test environment supports a broad range of MEMS test applications with a standardized set of thermal management capabilities.

by Centipede Systems

Conclusions

- *A MEMS qualification standard is a critical step towards a mature technology;*
- *The involvement of players operating at different levels in the MEMS sector is critical for a sound outcome;*
- *Investment and activities are necessary to mature available methodologies;*
- *Compromises will be necessary to achieve a satisfactory but relevant qualification standard;*
- *Non-coordinated steps have been already taken by private entities to address market needs;*
- *A collaborative approach based on open information exchange must drive the activities' dynamics on MEMS qualification;*

Q&A

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