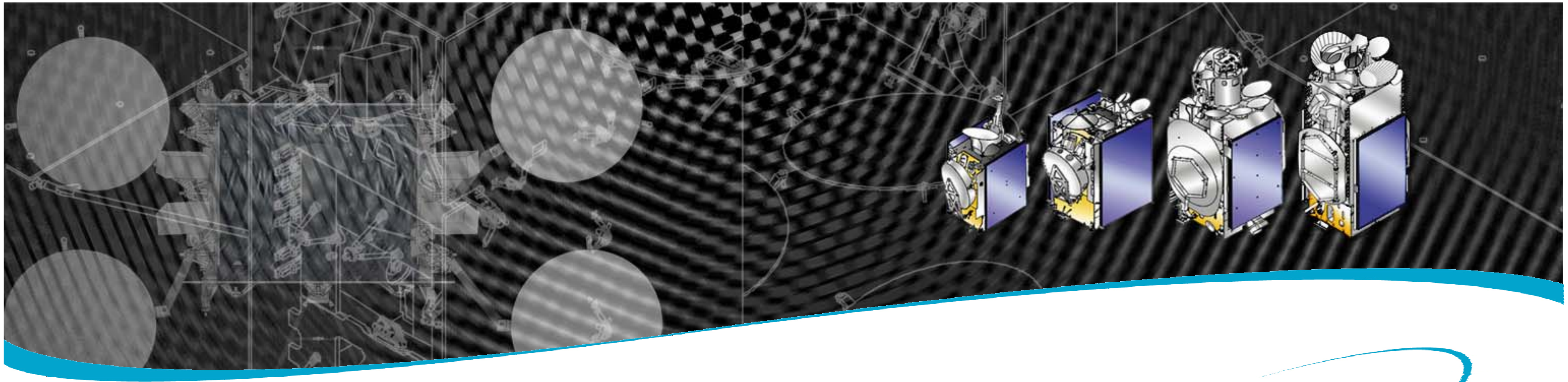

ThalesAlenia Space
A Thales / Finmeccanica Company

Space Qualification Approach for MOEMS Technologies

MNT Workshop 2007, ESTEC, The Netherlands

October 11th, 2007

A. Bensoussan

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THALES

Industrial Unit Electronics, Thales Alenia Space

Date Oct 11th, 2007

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Micro (Opto) Electro Mechanical structures, as identified in the 5 years MNT Strategic dossier published by CTB WG, are MEMS with the ability to alter or modulate a light beam by reflection, diffraction or refraction.

They combine optical, mechanical and electrical functions.

MOEMS is an enabling technology for some applications, such as optical communication and projection display.

Context and challenges

MOEMS devices are promising for the implementation of on-board optical communication systems with high bandwidth (several GBit/s), thanks to their low consumption, low volume and low mass. They can be used as:

- **Optical switches** for redundancy switching or low-port-count switching
- **Switching matrices** of optical cross connects for medium and high-port-count signal routing
- **Variable Optical Attenuators (VOA)** to balance power levels among channels
- **Tunable optical filters** (such as Fabry-Perot) to select different bands of wavelength for WDM
- **Tilting micro-mirrors** for the fine optical beam steering and tracking to support free space optical links.

Optical payload applications as:

- Telecommunications,
- On-board data-handling,
- Data communications

might be incorporating MOEMS devices.

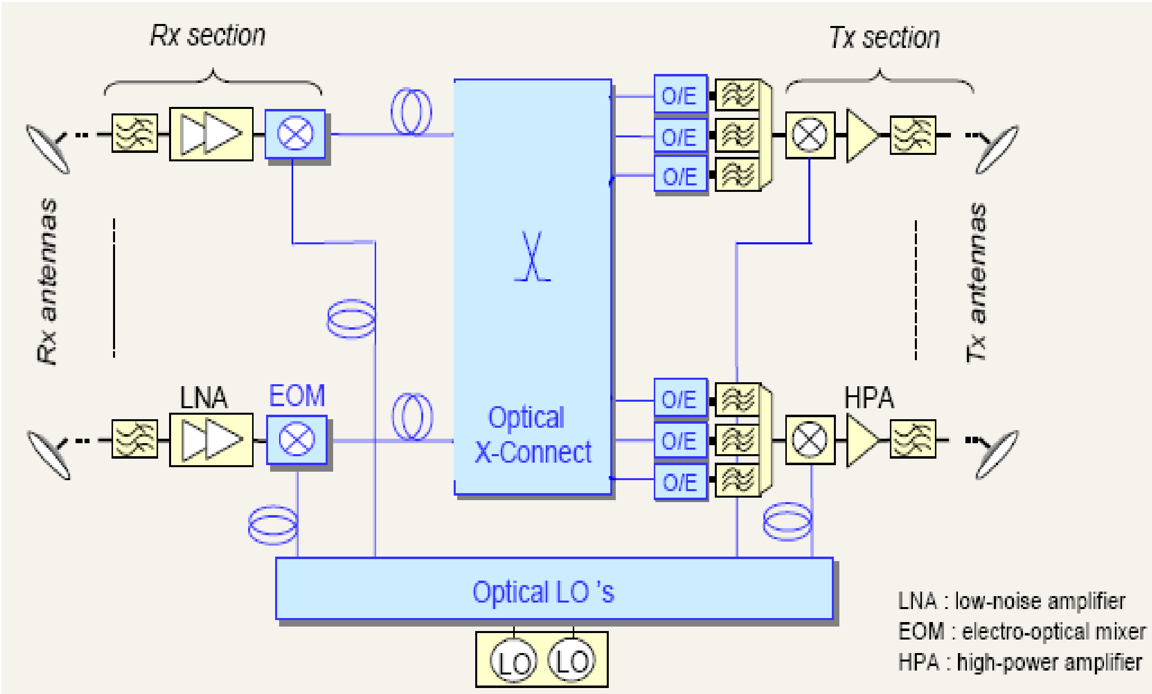
Context and challenges

Generic architectural concept

- optical distribution of centralised LO's
- optical frequency down-conversion
- optical cross-connection of µ-wave channels

Merits

- flexible beam-to-beam connectivity
- broadband, frequency-independent design
- scalable to large sizes
- low mass & volume, power consumption

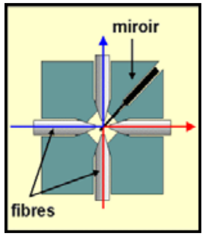


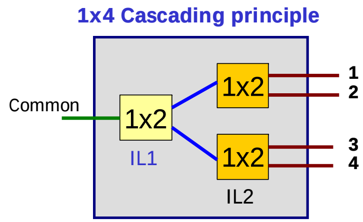
Application example: a schematic of opto-*microwave transparent repeater* (after SAT 'N LIGHT project)

Context and challenges

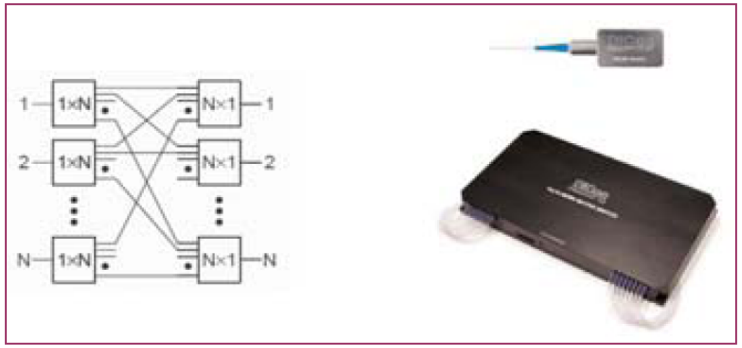
Using MOEMS switch architectures available on the market 1/2

- Elementary 1x2 and 2x2 switches
  - ✓ **SERCALO, DICON, NORTHROP GRUMMAN, …**

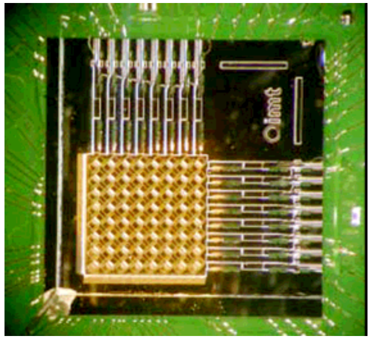




- Hybrid assemblies of discrete 1x2 and 1xN switches
  - ✓ **Any connectivity,**
  - ✓ **Matrices as Spanke network**
  - ✓ **SERCALO, DICON (up to 24x24)**



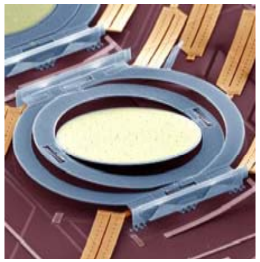
- Integrated 2D crossbar switches
  - ✓ **Planar matrices with digital control,**
  - ✓ **Complexity grows as N^2**
  - ✓ **Single-sided or double sided**
  - ✓ **AT&T, OMM, SERCALO**

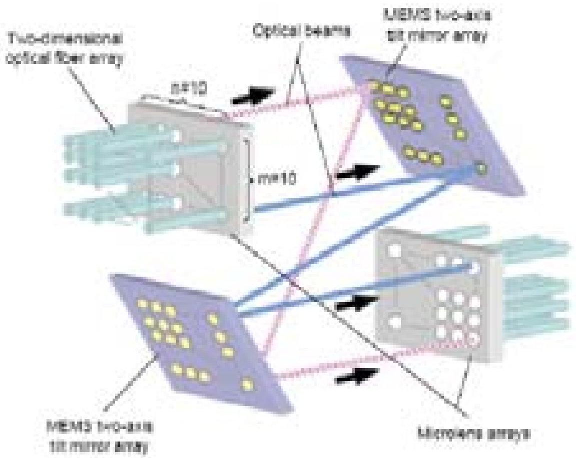


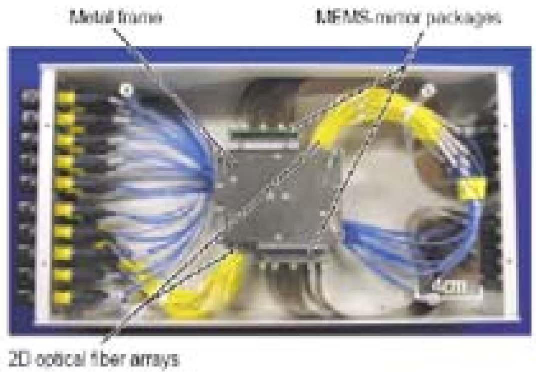
Context and challenges

Using MOEMS switch architectures available on the market 2/2

- Analog, free-space MOEMS switches
  - ✓ **linear mirror arrays, with analog 2D steering, …**
  - ✓ **mirror matrices with analog 3D steering**
  - ✓ **complexity grows as 2.N**
  - ✓ **Folded, unfolded architectures**
  - ✓ **LUCENT, Glimmerglass, NTT, FUJITSU**







- Early demonstrators of MOEMS based microwave photonic sub-systems have confirmed feasibility and proved excellent RF performance.
- Preparing the future, is now to consolidate (and industrialize) these technologies able to be used under space constraints.

M(O)EMS ∆ Qualification study

∆Space Qualification objective study : to define and evaluate qualifications tests sequences defined as close as possible to these constraints (and above), in order to assess MOEMS product limits when placed under these application domains.

(“∆” wording means based on existing TELCORDIA and MIL-STD qualification normative documents reconsidered.)

Phase 1

- Survey of Micro Optical Electro Mechanical Systems (MOEMS).
- MOEMS Suitability for Space Applications and Technology Maturity Level.
- Space Qualification Definition, Effort for Δ Qualification, MOEMS selection

Phase 2

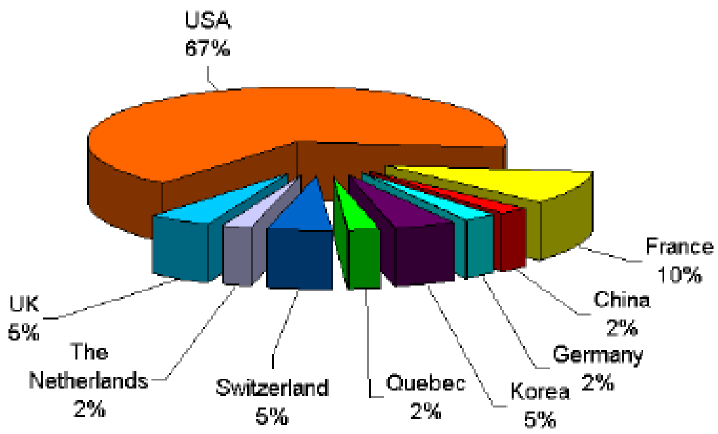
- Consolidation of Δ Space Qualification Definition, Procurement of selected MOEMS.
- Δ Space Qualification Testing and Reporting.

M(O)EMS market survey

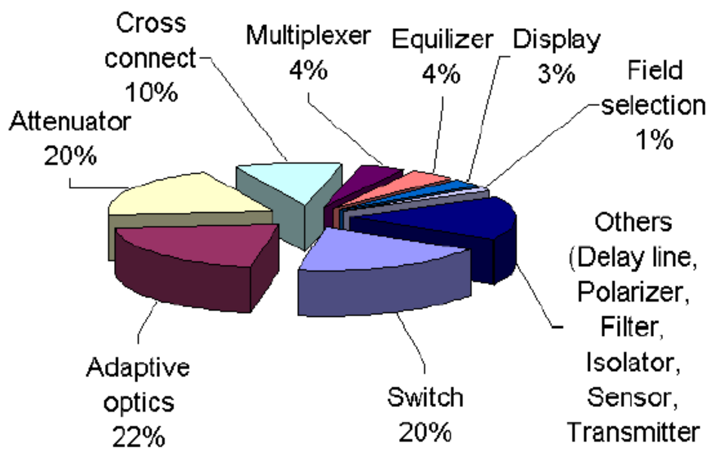
Data base construction

- Up to 100 companies contacted
- Identify companies which are real market players, which have theirs own MOEMS products
- Companies proposing commercial MOEMS products
- database completed
  - more than 100 datasheets downloaded
  - more than150 papers
- Data base completed at the end of 2006 (phase 1).

MOEMS Market players (2005)



Family panorama



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ESA/MIL/TELCORDIA standards

A full comparison between existing standards (Test methods from ESA, MIL and TELCORDIA): ECSS-Q-60-05 for hybrids, ESCC9010 for ICs, ESCC3702 for switches, ESCC3602 for relays, Telcordia GR-1209 Generic requirements for passive optical components, Telcordia GR-1221 Reliability assurance for passive optical components, Telcordia GR-1073 Generic requirements for single mode fiber optic switches.

A strong effort and fruitful exchange of background between all partners help to identify for and against test methods applicable to MOEMS.

MIL-STD-883 & 750: Advantages, drawbacks, implementation ability, effectiveness, availability, have been ranked for each of them:

MECHANICAL TESTS		
Insulation resistance MIL-STD-883, method 1003	NR	+ Required for high control voltage + ESD test seems more relevant for MEMS/MOEM
Moisture resistance MIL-STD-883, method 1004.7	M	Main failure cause
PERFORMANCE CHARACTERIZATION TESTS		
Thermal, electrical and optical characteristics MIL-STD-883, method 1012.1 and other for electrical and optical	M	Relevant for space application.
ENVIRONMENTAL OPERATING TESTS		
Damp heat MIL-STD-202. Method 103 or IEC 68-2-3. 85_/85%RH /1000hrs	M	Results used for FIT rate estimates
Burn-in test MIL-STD-883, method 1015.9	M	Burn-in test is specific for IC circuits and packages. Should be optimized and adapted for MEMS/MOEMS
OTHER ENVIRONEMENTAL TESTS		
Constant acceleration MIL-STD-883, method 2001.2	NR	Not necessary, shocks are more representative
Mechanical shocks MIL-STD-883, method 2002.4	M	ESA standard compared to Telcordia: shorter and more powerful
Solderability MIL-STD-883, method 2003.8	M	The materials that will replace tin lead should be qualified for space.

M(O)EMS ∆ Qualification exercise

INITIALLY 25 DEVICES + 4 Bare dice

SG 1/ Thermo-integrity
4 devices + CD

- Temperature cycling (m1010.8)
  cond. A (-55°C, + 85°C) 50Cy.
  cond. A (-55°C, +100°C) 50Cy.
  →100 cy. pass/fail
  cond. B (-55°C, +125°C)
  #Cy. Up to 50% lot fail
- IMEC
  Alternative test for Sealing integrity

SG 2 / Thermo-Electrical
8 devices + CD

- Electrical / Optical characteristics at room, high and low temperature (m1012.1)
- Moisture resistance
  5 cy. -40°C to +75°C, RH 90% only controlled at 75°C
- Thermal Shocks
  5 cy., -55, +125°C
  (m 1011.9)

3 Devices	5 Devices
ESD testing (m3015.7)	Moisture resistance 10 cy. -40°C to +75°C, RH 90% only controlled at 75°C (m1004.7)
IMEC Alternative test for Sealing integrity	Thermal Shocks 5 cy., -55, +125°C (m 1011.9)

Do While:
lot failure rate
<=40%
or
5 loops

SG 3 / Mechanical & endurance
6 devices + CD

- Vibration Fatigue (m2007.3)
- Mechanical shocks (m2002.4)
- Endurance test at high Temp & Under Vacuum (m1033)

SG 4 / Miscellaneous
6 devices + CD

- Radiation tests (m1019.6)
- RGA (m1018.4)
  2 devices
- Out gassing test
  4 devices
- CONSTRUCTIONAL ANALYSIS
  2 devices + 4 Bare dice including
  Lead Integrity & Bending test
- Rapid depressurization (m1001)

M(O)EMS Δ Qualification exercise

The test exercise was conducted on 2 MOEMS manufacturers **(Optical switch and VOA):** 25 samples (+10 bare dice) from each manufacturer.

Each lot was characterized, screened and tested according to the Δ Qualification flow including :

Electro-Mechanical,
Environmental,
and Miscellaneous test groups (Radiation, CA, Out gassing…).

THERMO-INTEGRITY TESTS GROUP

The goal is to assess the internal package assembly robustness and temperature cycling.

As the products are new and have internal mechanical parts it was decided to start with 3 step of stress from a low temperature range to an increased range up to the final usually implemented for space (i.e. 100 cy at –55°C to + 125°C).

THERMO-ELECTRICAL TESTS GROUP

The goal is to characterize the devices in the temperature range compatible to space application in order to confirm the maximum rating temperature values with the corresponding set of opto-electrical parameters.

The second part of the Thermo-Electrical sub-group is to assess the behavior of the devices when submitted to external humidity and temperature stress step sequences: this series of test with a loop has been defined to progressively identify the limits of the products in order to derive some recommendations for the final methodology.

ENVIRONMENTAL TESTS GROUP

The goal is related to mechanical stress applied to the products either to stress the package integrity or to stress the MOEMS mechanical parts included into the dice.

Vibration fatigue (supposed to be the most representative equivalent stress seen during the launch of the satellite) and the mechanical shocks are defined in series with standard space level of strains.

At the end an endurance test at high temperature and under vacuum is proposed in order to simulate the space environment and to verify if vacuum (including rapid depressurization stress) may have an impact on the reliability of the products, especially when it is not clear if the MOEMS package can be considered as hermetic.

MISCELLANEOUS TESTS GROUP

The goal is to address product manufacturing and industrialization suitable for space application and environment.

Sequence details radiation testing together with constructional analyses and material behavior under vacuum including RGA and out gassing tests (for contamination risk, if any, on optical structures) or rapid depressurization to demonstrate that the package integrity may be safe during rocket launch.

M(O)EMS Δ Qualification exercise

Thermo-Mechanical Test Group

- SG 1: Thermo-integrity 4 devices
  - Temperature cycling (m1010.8) — ESA
  - DAMP HEAT — SERCALO
- SG 2: Performance Characterization 8 devices
  - Electrical / Optical characteristics at room, high and low temperature (m1012.1) — SERCALO
  - Moisture resistance (m1004.7) — SERCALO
  - Thermal Shocks (m 1010.8 with dual chamber) — SERCALO
  - 3 Devices: ESD testing(m3015.7) — IMEC
  - 5 Devices: Moisture resistance (m1004.7) — SERCALO
  - DAMP HEAT — SERCALO

Environmental Test Group

- SG 3: Mechanical & endurance 6 devices
  - Vibration Fatigue(m2005.2) — ESA under SERCALO responsibility
  - Mechanical shocks (m2002.4) — ESA under SERCALO responsibility
  - Endurance test at high Temp & Under Vacuum (m1033) — Already done by SERCALO

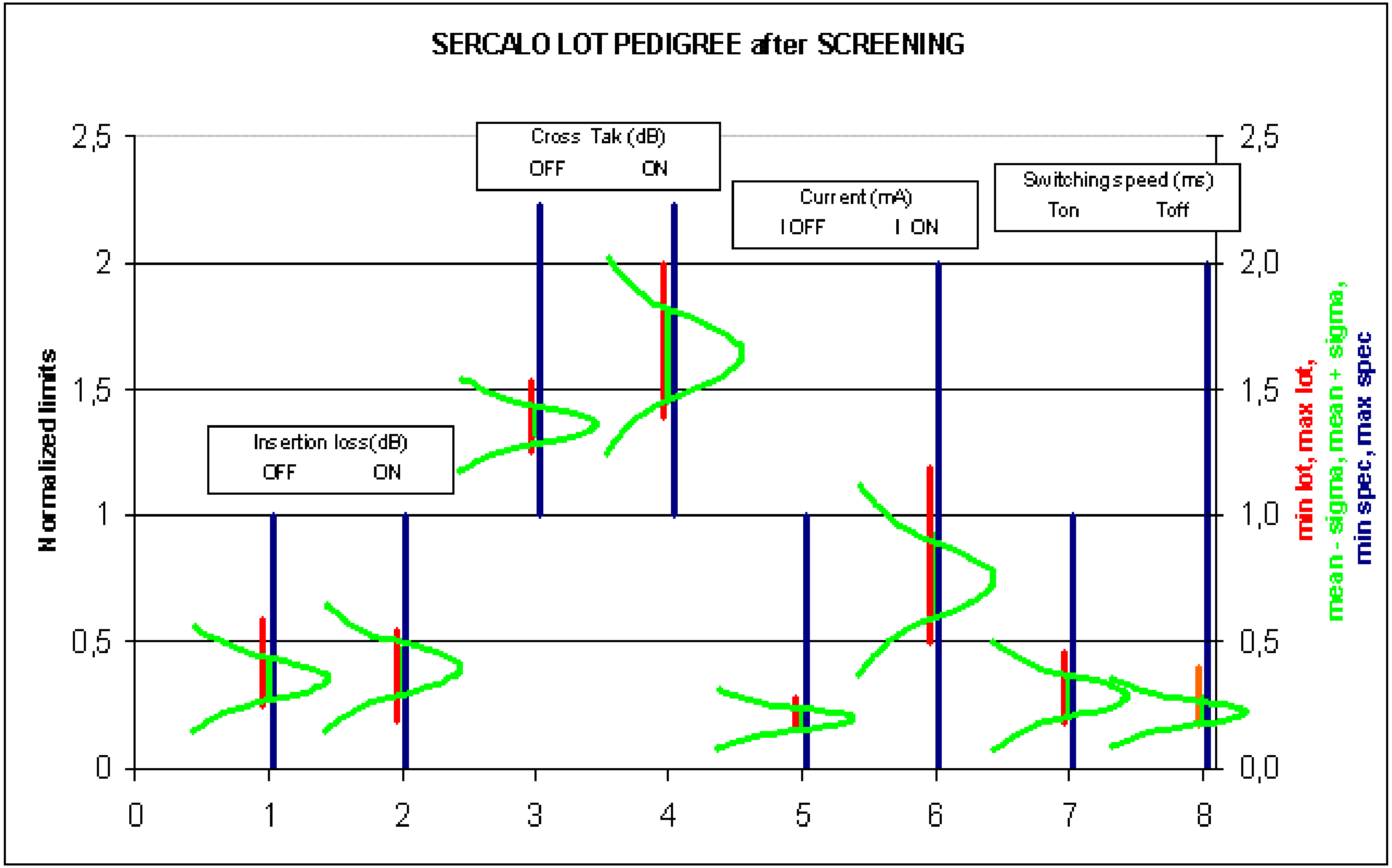
Miscellaneous Test Group

- SG 4: Miscelaneous 6 devices
  - Radiation tests (m1019.6) — ESA
  - 2 Devices: ***NOT applicable*** RGA (m1018.4)
  - 4 Devices: Out gassing test — ESA
  - CONSTRUCTIONAL ANALYSIS — ESA
  - Rapid depressurization (m1001) — IMEC

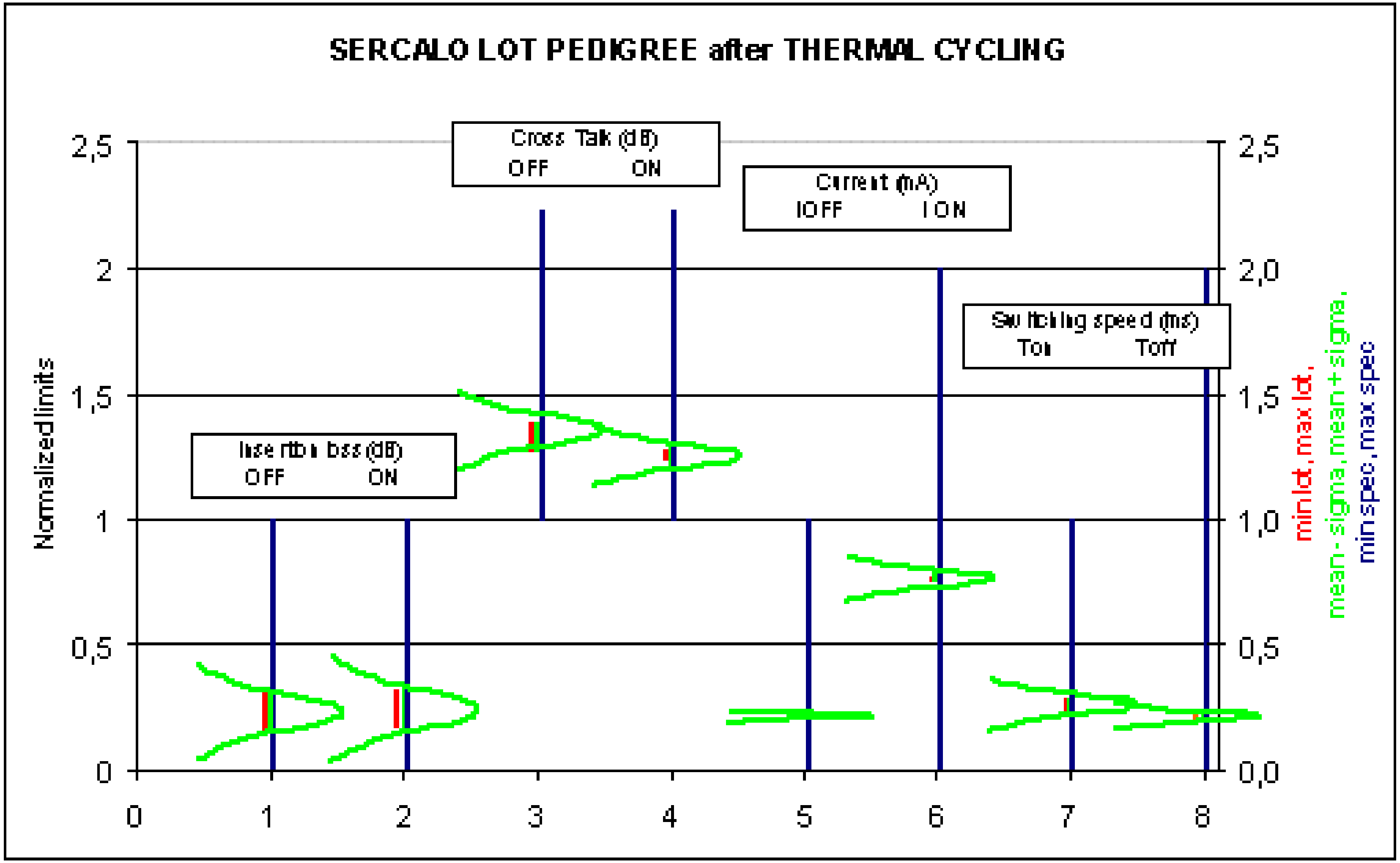
+ 1 Control Device for all Test Groups

SERCALO

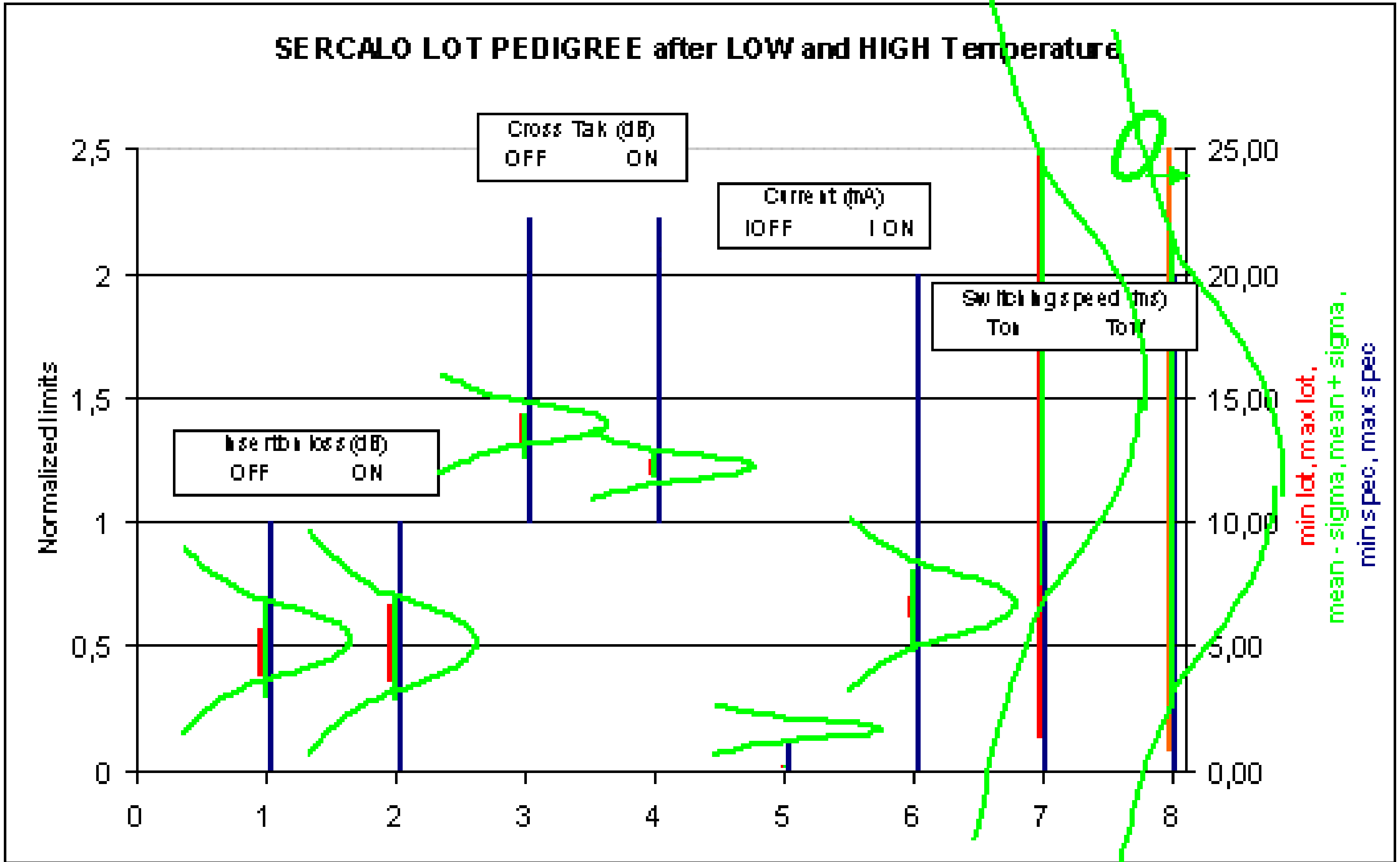
Do While:
lot failure rate
<=40%
or


SERCALO LOT PEDIGREE after SCREENING
Normalized limits
Insertion loss(dB)
OFF ON
Cross Tak (dB)
OFF ON
Current (mA)
I OFF I ON
Switching speed (ms)
Ton Toff
min lot, max lot,
mean - sigma, mean + sigma,
min spec, max spec
0 0,5 1 1,5 2 2,5
0,0 0,5 1,0 1,5 2,0 2,5
0 1 2 3 4 5 6 7 8

M(O)EMS ∆ Qualification exercise



M(O)EMS Δ Qualification exercise



M(O)EMS Δ Qualification exercise

Thermo-Mechanical Test Group

SG 1: Thermo-integrity – 4 devices
- Temperature cycling (m1010.8) – MEMSCAP

SG2: Performance Characterization – 8 devices
- Electrical / Optical characteristics at room, high and low temperature (m1012.1) – IMEC
- 2 Devices: ESD testing(m3015.7) – IMEC
- 4 Devices: Moisture resistance (m1004.7) – MEMSCAP

Environmental Test Group

SG 3: Mechanical & endurance – 6 devices
- Vibration Fatigue (m2005.2) – IMEC
- Mechanical shocks (m2002.4) – MEMSCAP
- Endurance test at high Temp & Under Vacuum (m1033) – THALES

Miscellaneous Test Group

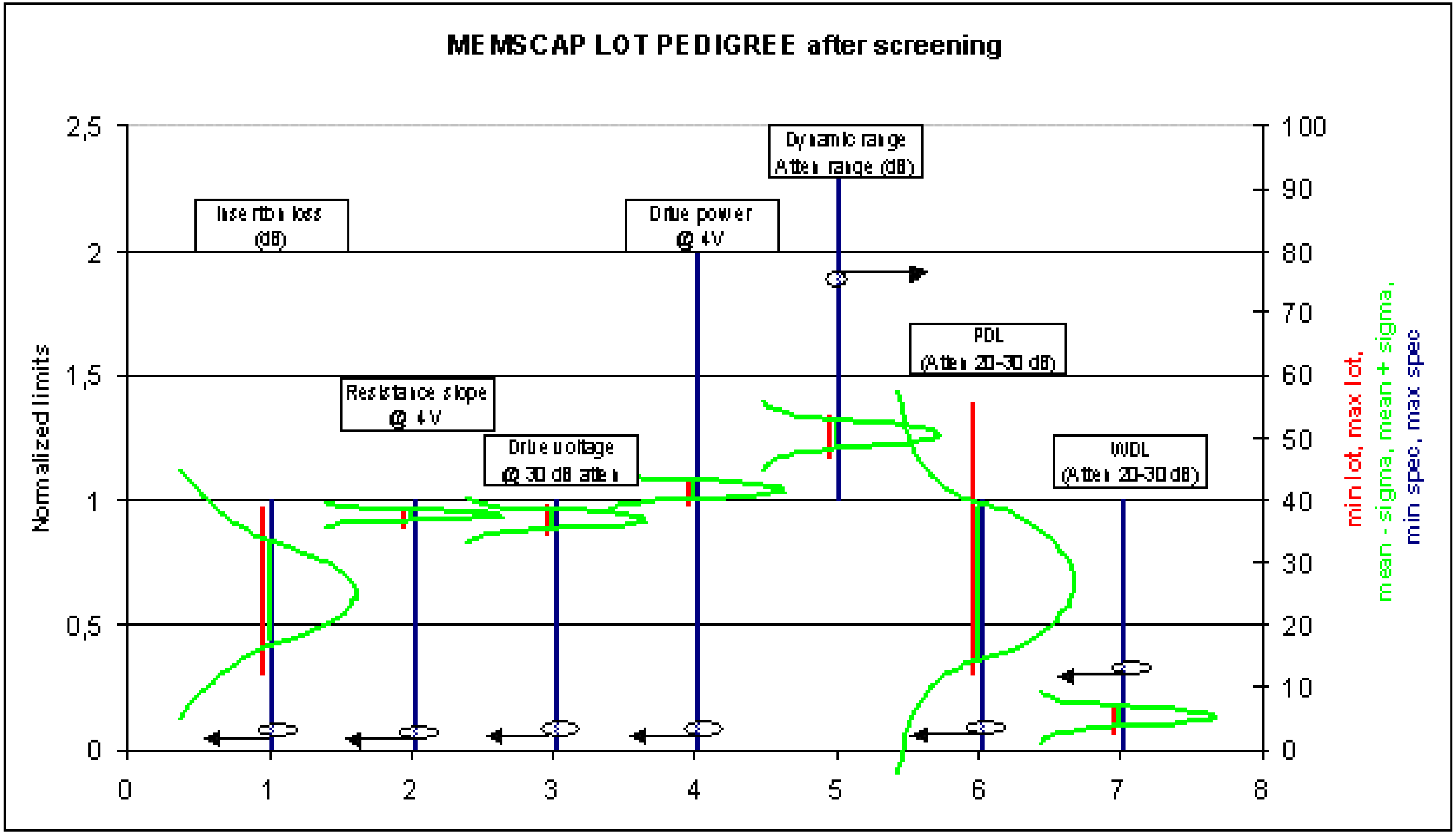
SG4 Miscelaneous – 6 devices
- Radiation tests (m1019.6) – ESA
- 2 Devices: RGA (m1018.4) – ORS; CONSTRUCTIONAL ANALYSIS – ESA
- 4 Devices: Out gassing test – ESA; Rapid depressurization(m1001) – IMEC

+ 1 Control Device for all Test Groups

MEMSCAP

THALES

M(O)EMS ∆ Qualification exercise



Results and Failure origins (1/2)

➢ Screening data

- Screening process didn't reveal infant mortality behaviour.
- Insertion loss, PDL and WDL are parameters complicated to be characterized (reproducibility, large dispersion, precision not guaranteed). Measurement techniques to be demonstrated or even improved for reliability assessment.
- Main failures observed at fiber input and output connectors due to handling and interim characterization.

➢ Thermo-electrical group

- Thermal cycling and damp heat are conclusive (but we observed dispersions on insertion loss parameter)
- Temperature cycles conclusive (no failure)
- ESD stress test with no failure identified.
- Moisture Resistance and Thermal Shocks are successful (no failure observed)

Results and Failure origins (2/2)

➢Environmental group

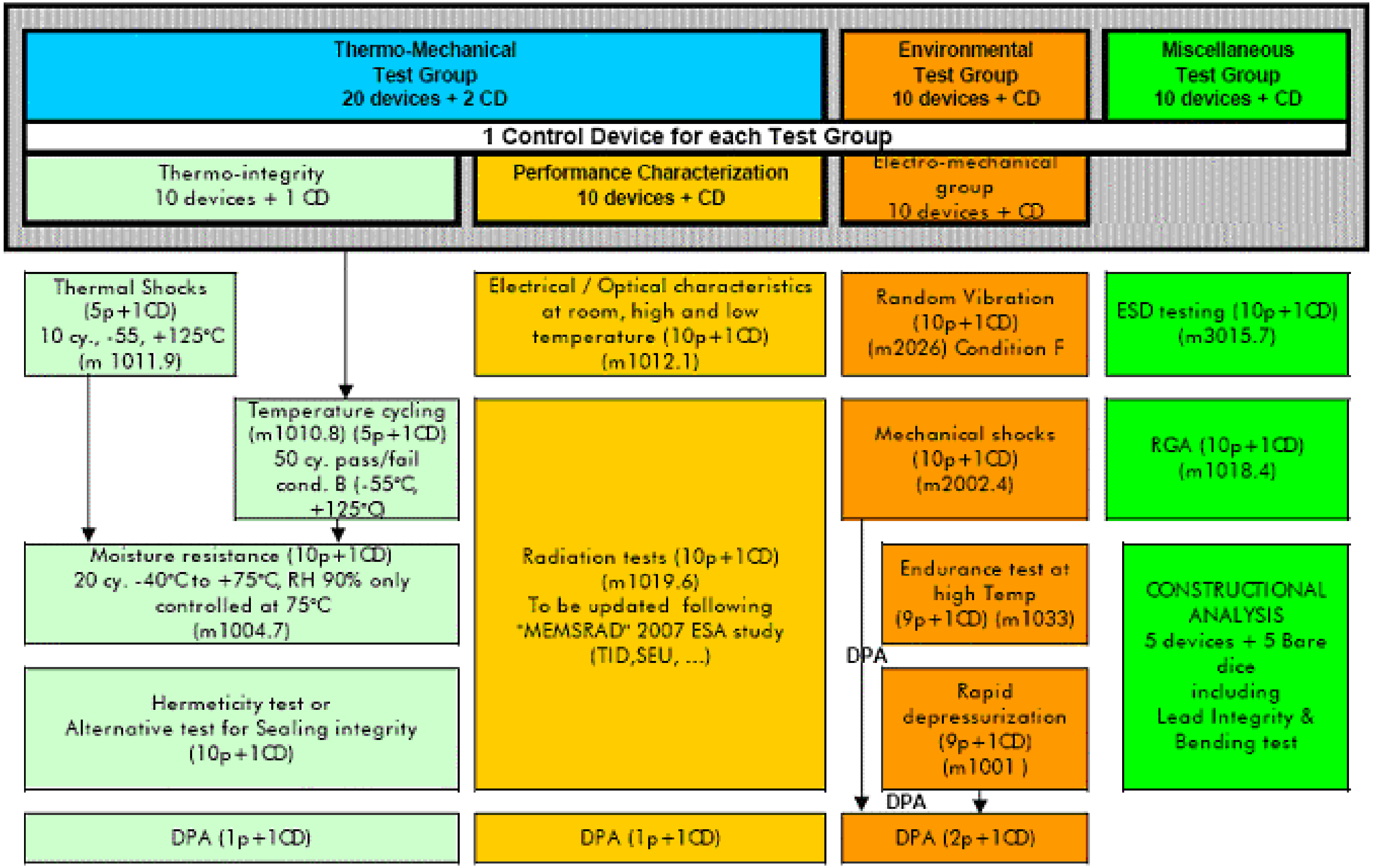
- Only failures at fibers level: handling or mechanical failure on PCB. Need to secure connections handling during the test.
- Vibration an mechanical shocks are successful (no failure)
- Endurance high temp and vacuum : conclusive but vacuum is not necessary implementing as no change in optical characteristics.

➢Miscellaneous group

- Radiation tests: Failures observed on IC COST electronic command. MOEMS not affected, Switch recovers and still working after electronic part replacement.

THALES

M(O)EMS new standard for ECSS or ESCC ?



Results and lessons learnt (1/3)

- MOEMS devices are TML3 to TML4 maturity for space application.
- TELCORDIA standard is not enough to cover space requirements and Delta Qualification program added or more stringent conditions:
  - Radiations tests,
  - ESD, RGA, Out gassing and Rapid depressurization,
  - Thermal shocks and Moisture resistance (test in series and loop proposed),
  - Mechanical shocks, Vibration variable frequency and Endurance life test under vacuum,
  - Thermal cycling (-55, +125°C) and alternative test method for hermeticity.

Results and lessons learnt (2/3)

- Test conducted at various facilities including: SERCALO, MEMSCAP, IMEC, Thales Alenia Space.
- Opto-electrical tests at nominal room temperature are critical and need to be carefully implemented: some opto-electrical parameters are sensitive to fiber bent and require attaching fibers to the test equipment set (to reduce mechanical vibration).
- Measurement reproducibility is tough to achieve and needs safe (ESD) and dedicated test room.
- Radiation tests need to be performed with a care test jig design in order to avoid EMC or oscillation.
- ESD test are difficult to implement as some devices are with (and other without) electronic parts inside the module.

Results and lessons learnt (3/3)

- Environmental endurance test under vacuum performed successfully. Not needed to have vacuum. Identification of critical parameters for reliability assessment.

- Endurance under vacuum was also intended to assess the effect of the rapid depressurization test (around 5 10^{-5} bars after 9 mn at each interim electrical measurement sequence).

- PDL and WDL parameters are not confirmed to be used for quality and reliability verification: they are to much sensitive (measurement dispersion) for environmental test conditions or we need to define the test set up with extreme care.

- Generic qualification flow chart identified and adapted for each manufactured. Global methodology proposed and to be generalized.

Conclusion

Several benefits and know-how achieved.
Good European collaboration and fruitful contributions.
Space Qualification methodology drawn and tested with important and major lessons learned.

Nevertheless, MOEMS in space will require maturity at multiple levels:

- **Products designed, industrialized and manufactured for space harsh environment,**
- **Equipment designed for new enabling architectures demonstrating the benefits of MOEMS instead of standard products (cost and technical benefits must be demonstrated),**
- **User manufacturing and testing in mature environments (learning curve to be initiated and maintained) : role of Agencies to promote these new technologies and help to built a new age of techniques (opto and nanosystems)**

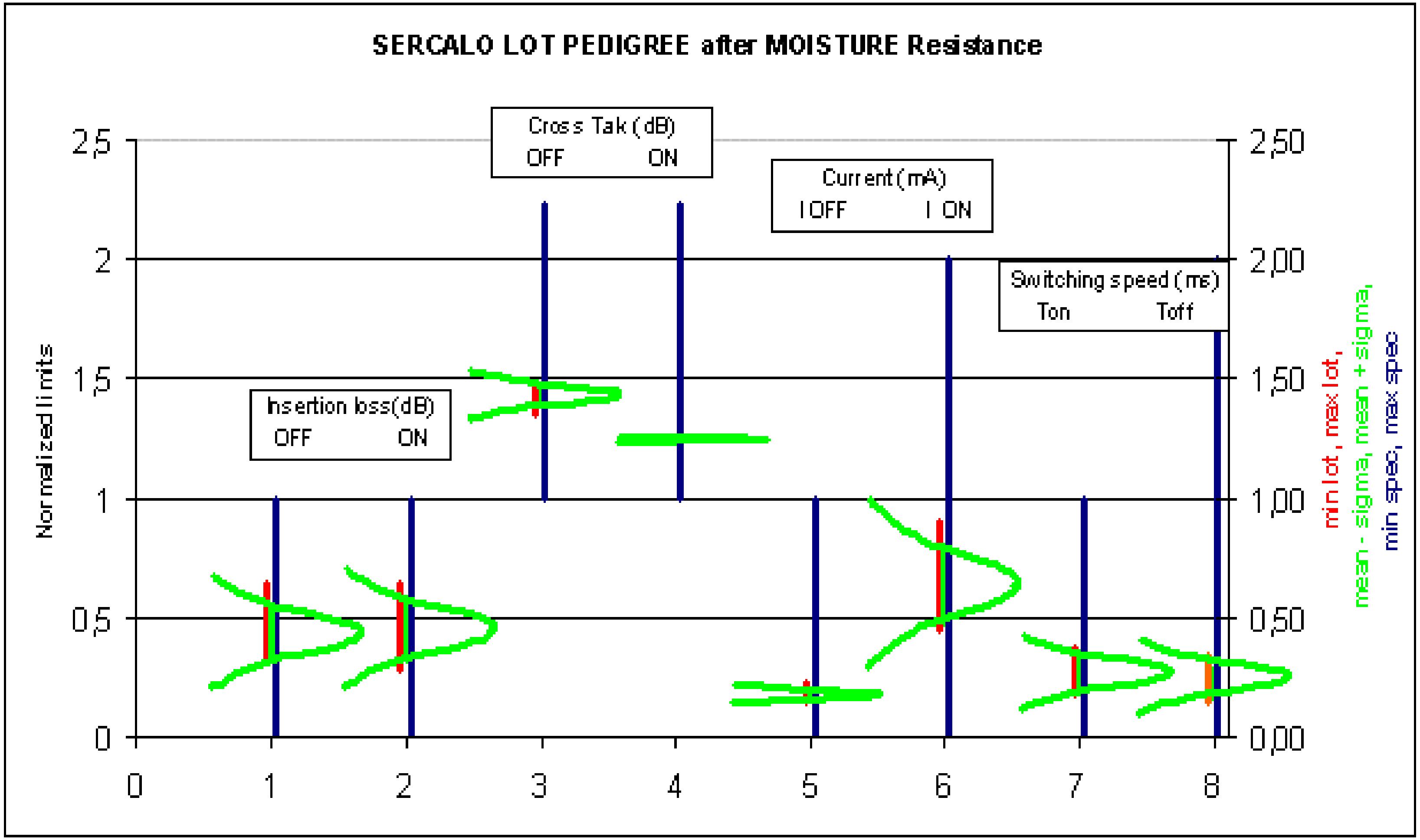
Acknowledgements

This work has been supported by ESA under a 2 years study n°18669/04/NL/CP – "*M(O)EMS Delta Qualification Methodology*"

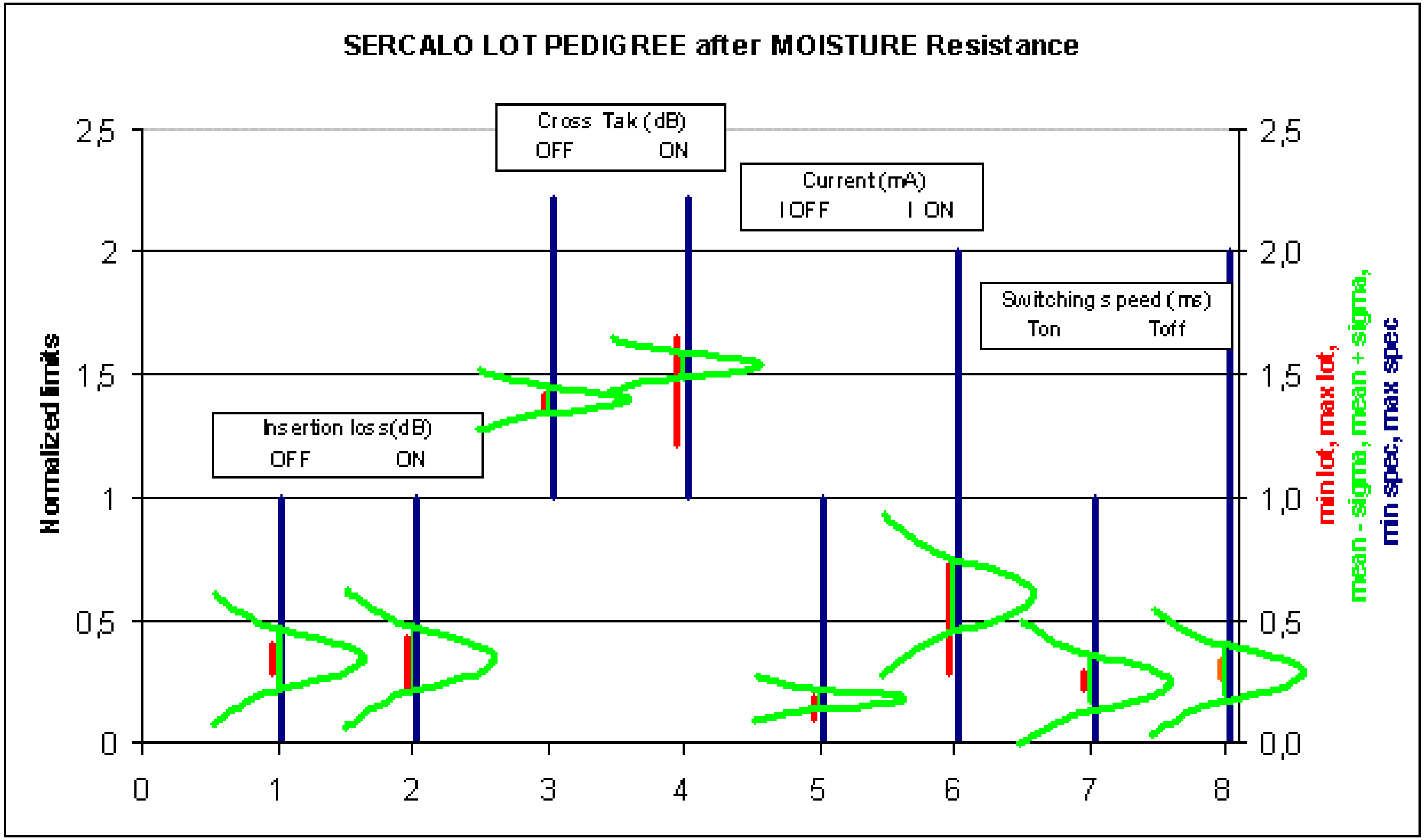
Thanks to Laurent MARCHAND, Technical Officer at ESTEC, and to our Partners in this project for the fruitful cooperation.

Annexes

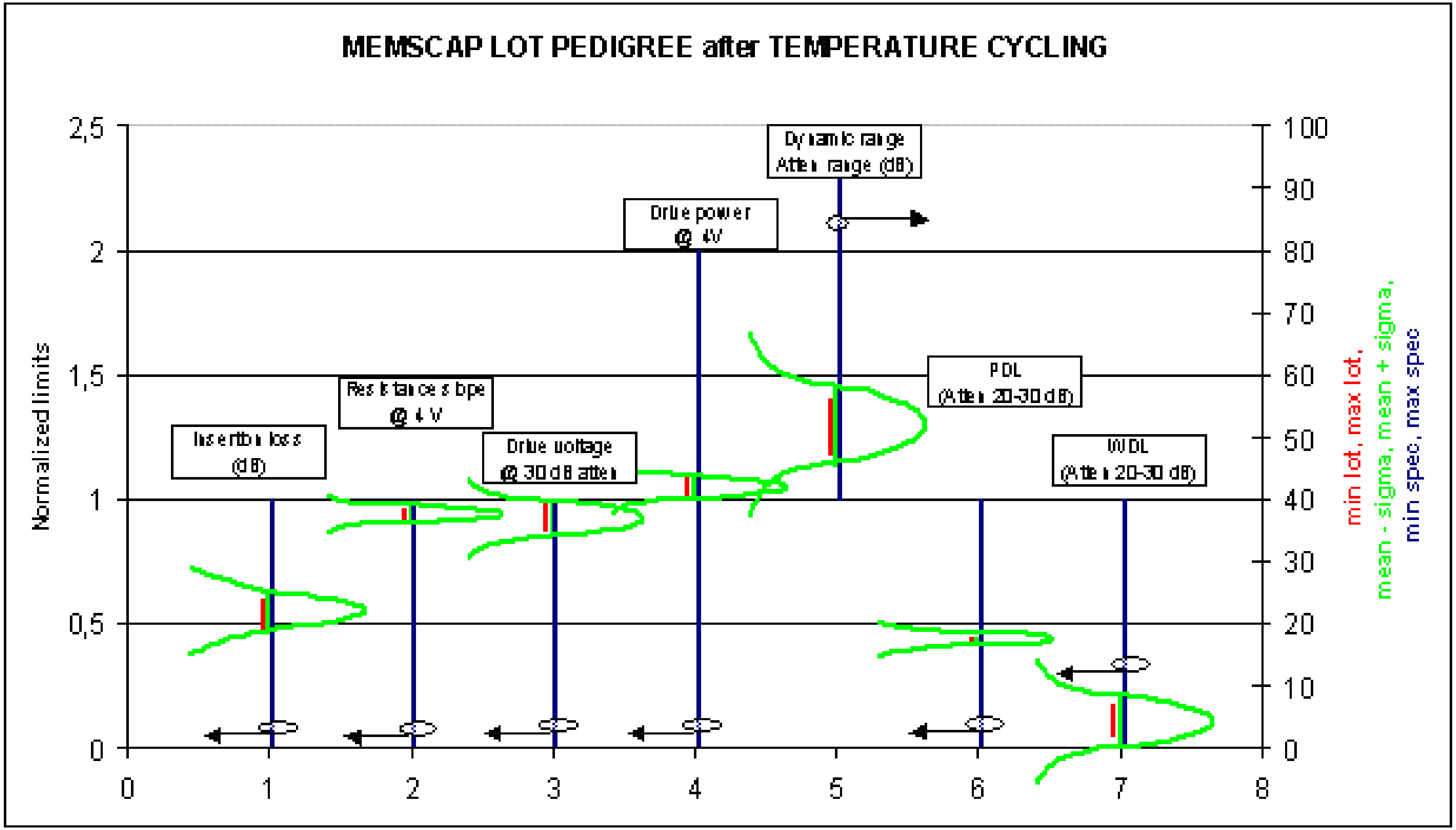
M(O)EMS Δ Qualification exercise



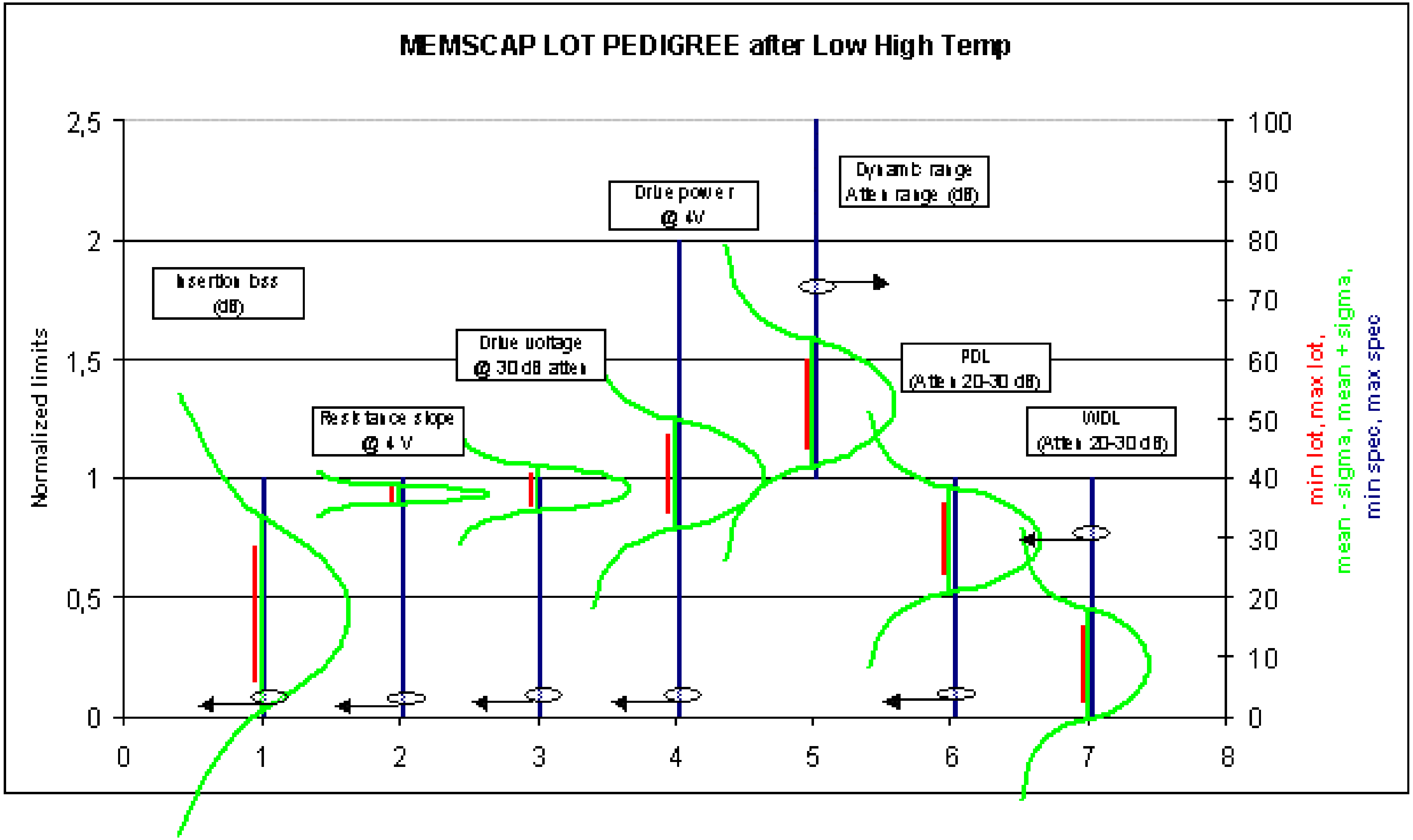
M(O)EMS ∆ Qualification exercise

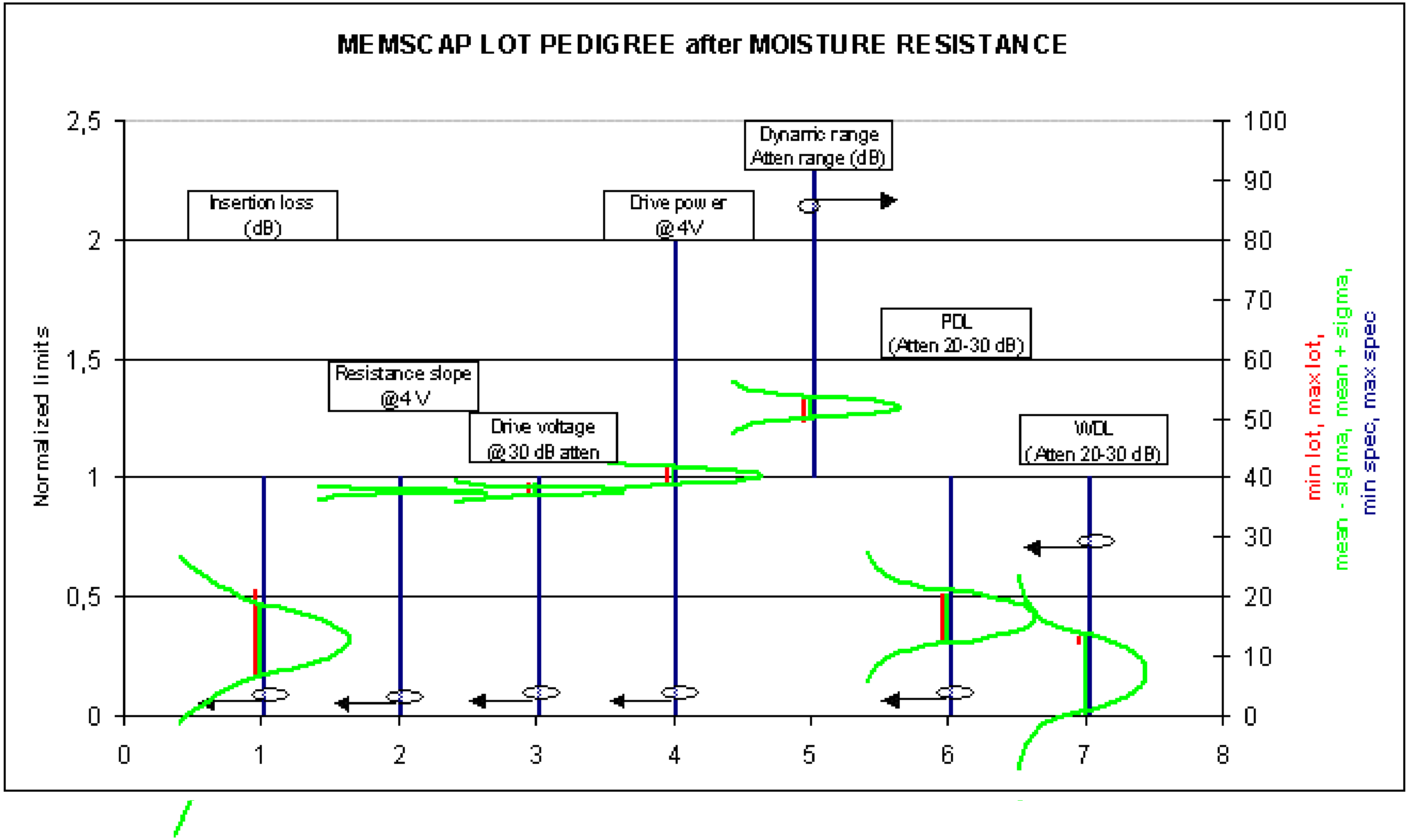


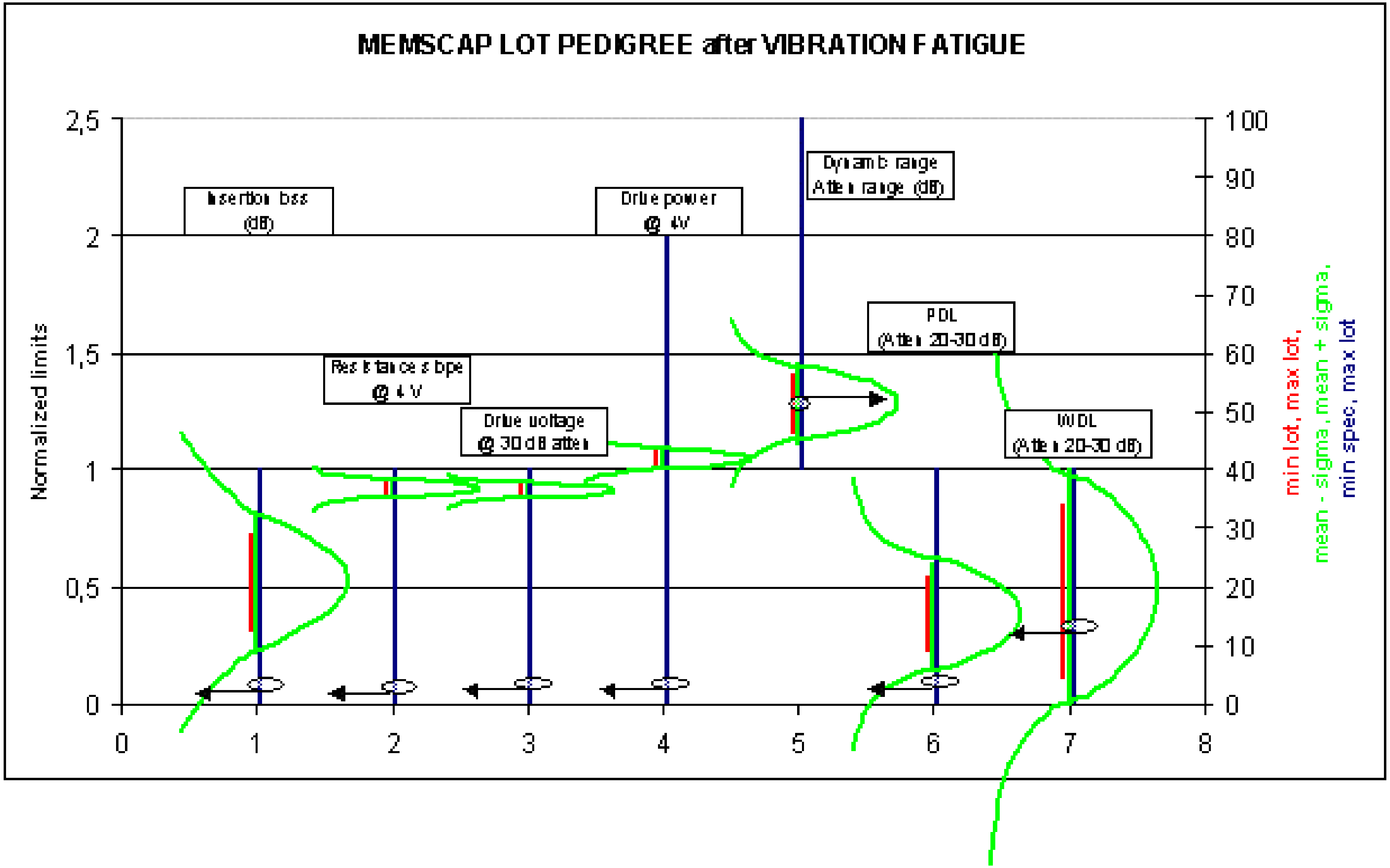
M(O)EMS Δ Qualification exercise



M(O)EMS Δ Qualification exercise




MEMSCAP LOT PEDIGREE after MOISTURE RESISTANCE
Normalized limits
Insertion loss (dB)
Resistance slope @4 V
Drive voltage @30 dB atten
Drive power @4V
Dynamic range Atten range (dB)
PDL (Atten 20-30 dB)
WDL (Atten 20-30 dB)
min lot, max lot,
mean - sigma, mean + sigma,
min spec, max spec
2,5
2
1,5
1
0,5
0
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8


MEMSCAP LOT PEDIGREE after VIBRATION FATIGUE
Normalized limits
min lot, max lot,
mean - sigma, mean + sigma,
min spec, max lot
Insertion loss (dB)
Resistance slope @ 4 V
Drive voltage @ 30 dB atten
Drive power @ 4V
Dynamic range Atten range (dB)
PDL (Atten 20-30 dB)
WDL (Atten 20-30 dB)