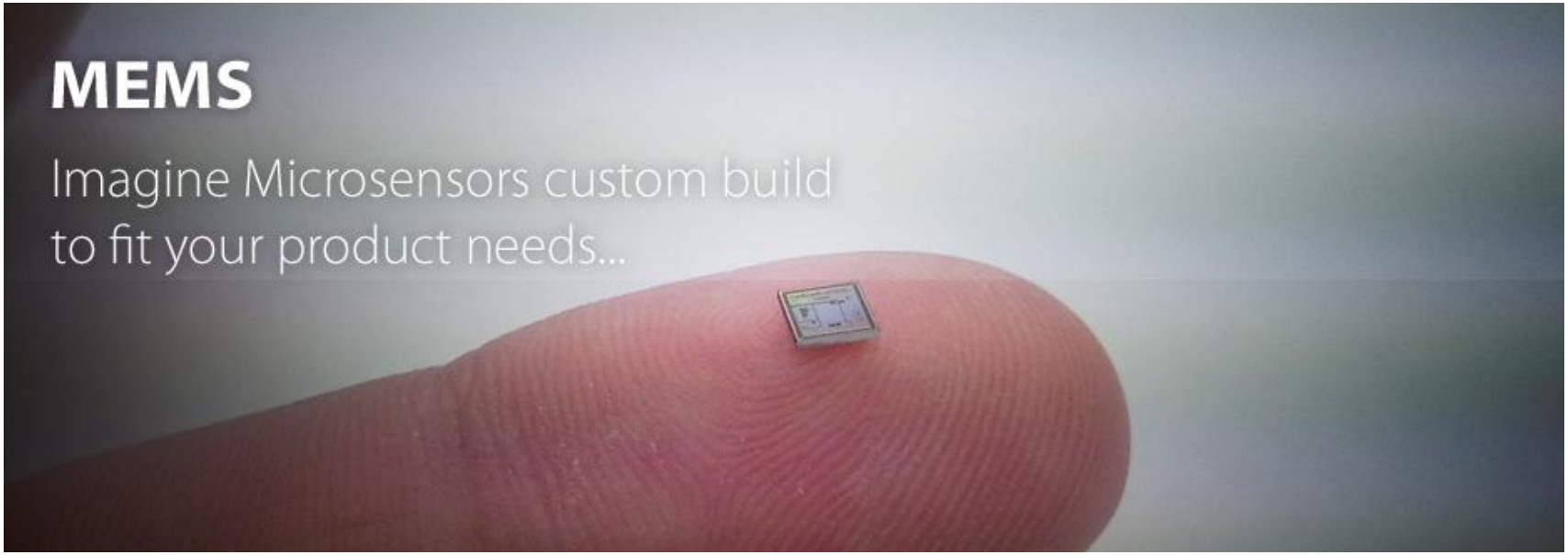


Performance Demonstration of THEON's existing Pressure Modules for Space Applications

Zervakis, M.; Mazarakis, G.; Spyropoulou, A.; Glykiotis, G.; Fikos, G.; Athanasopoulos, T.

ESTEC, 17 October 2012

www.theon.com

Outline

1. Introduction
   - THEON SENSORS SA profile
   - MEMS Business Unit technologies/capabilities
   - THEON-ESA related activities

2. Performance Demonstration of THEON's existing Pressure Modules for Space applications
   - MEMS transducer
   - ASIC
   - System Performance
   - Identification of space application and end-user

3. Current status of THEON pressure sensors
4. Outcome

Company Profile

- **Privately owned company established in 1997 and rapidly expanded in the world market**

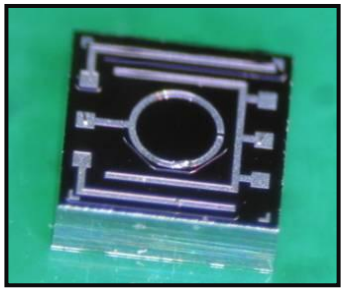
- **A *high technology* company with advanced design and development capabilities, *flexibility* and *custom made approach***

Electro-Optic Systems

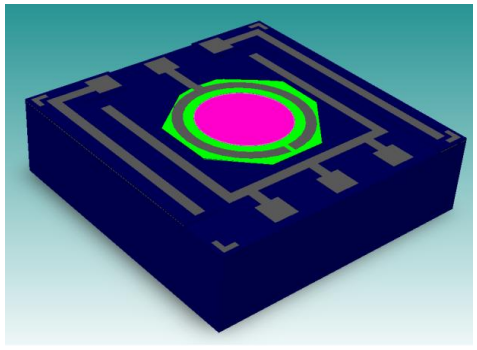
Design, development and manufacture of Electro-Optic Systems for defense and security applications

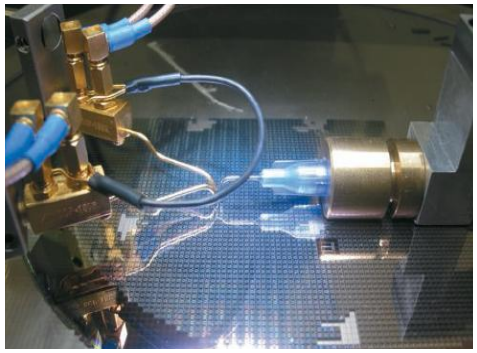
Micro Electronic Mechanical Systems (MEMS)

Design, development and production of customer-specific MEMS-based modules for aerospace, industrial, medical and consumer goods applications



MEMS Business Unit





- Fabless design and development house for customer specific sensing modules
- Full control and ownership of all aspects of our products
- Combined state of the art hardware and software for measuring
  - Airflow
  - Pressure
  - Acceleration
- Capability to design, develop and move fast to prototype in response to customer-specified systems
- From concept and design to low-medium-high volume production
- Targeting applications in the following markets
  - Medical, Industrial, Aerospace, Automotive, Consumer goods

Company Information
MEMS Business Unit Technology

- Design and Simulation of Silicon based micro sensors (MEMS)
- Design and Simulation of electronics, for signal conditioning and interfacing of micro sensors
- Design of MEMS Modules Mechanical Housing
- Design of substrates
- System packaging and microassembly / Wire and Die Bonding
- System integration and assembly
- Systems Testing and Characterization

Process technology

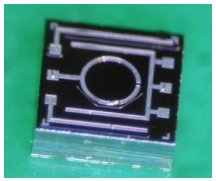
MEMS Capacitive Pressure Sensors (Proprietary)

MEMS Bulk Micromachining for Resistive Flow Sensors

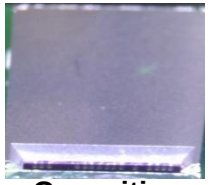
MEMS Surface Micromachining for Capacitive Inertial Sensors (Commercial)

0.18um Mixed-Signal CMOS (Commercial)

MEMS



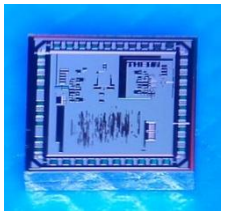
Capacitive Pressure Sensor



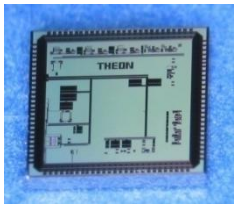
Capacitive Accelerometer

Flow

ASIC



Capacitive Interface

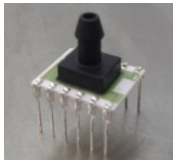


Resistive Interface

Products

Mass Flow meter

Pressure Sensor



Accelerometer

ESA activities

- **MEMS Pressure sensors**

  1. "Performance Demonstration of THEON's existing Pressure Modules for Space applications"
  2. "Space Qualified Family of MEMS Pressure Modules for Satellite Applications"

- **MEMS Accelerometers**

  1. "Feasibility Study for MEMS-SOI Capacitive Accelerometer "
  2A. "Flight Demonstrator for a MEMS Accelerometer for Launchers"
  2B. "Accelerometer Re-direction study"

Performance Demonstration of THEON's existing Pressure Modules for Space Applications

Activity started on Feb 2009 and successfully concluded on Sep 2011

Scope and objectives of activity :

- Pressure sensor technologies survey
- Identify potential space applications and end-user requirements
- Assessment of THEON's existing pressure sensing technology
- Design of a technology demonstrator for an identified space application
- Propose a development plan for the demonstrator

MEMS Pressure Sensor Technology

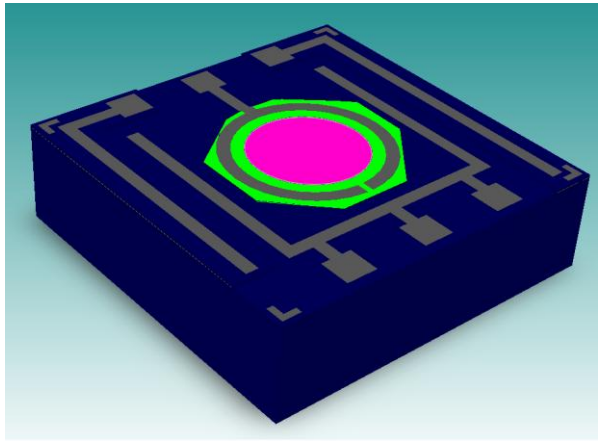
Principle of Operation

- Capacitive Sensing principle
- Motion of flexible silicon membranes under external pressure
- Absolute Operation

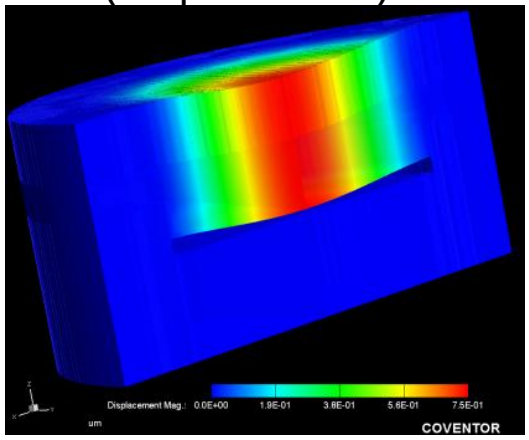
Features of Microfabrication Process

- Bulk Micromachining of SOI wafers
- Industrialized Frozen Process developed together with X-FAB
- Theon is the owner and exclusive user of the process and owner of any fabricated design

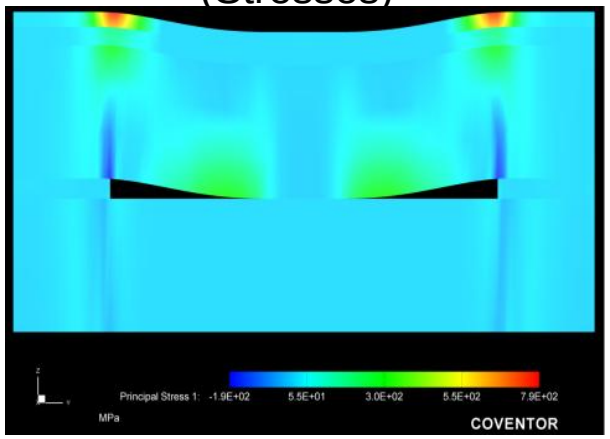
3D model



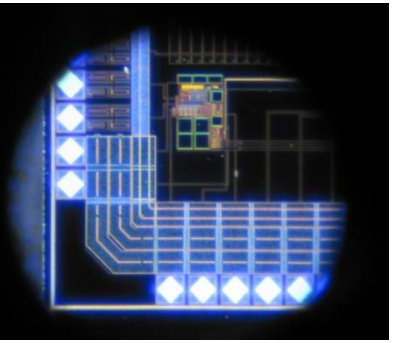
Simulation result (Displacement)



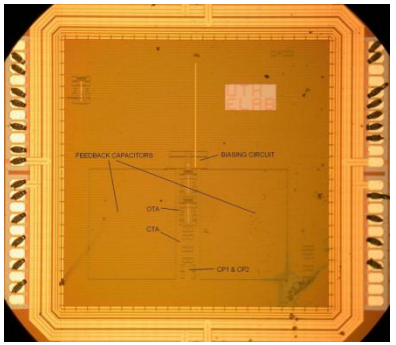
Simulation result (Stresses)

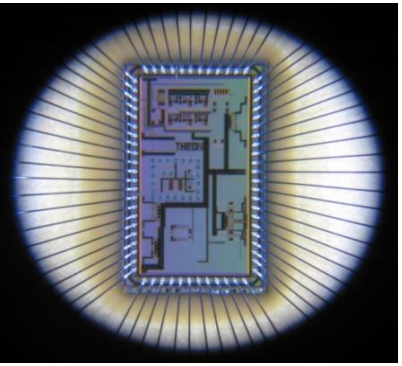


CMOS ASIC for pressure sensors

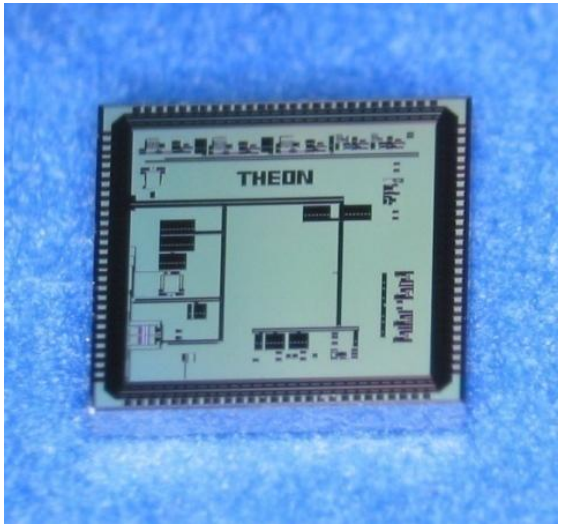


- Design analog, digital and mixed-signal integrated circuits for signal conditioning of MEMS sensors
- Full-custom circuit design with different CMOS technologies ranging from 1um down to 90nm
- System level simulations of both electronics and MEMS

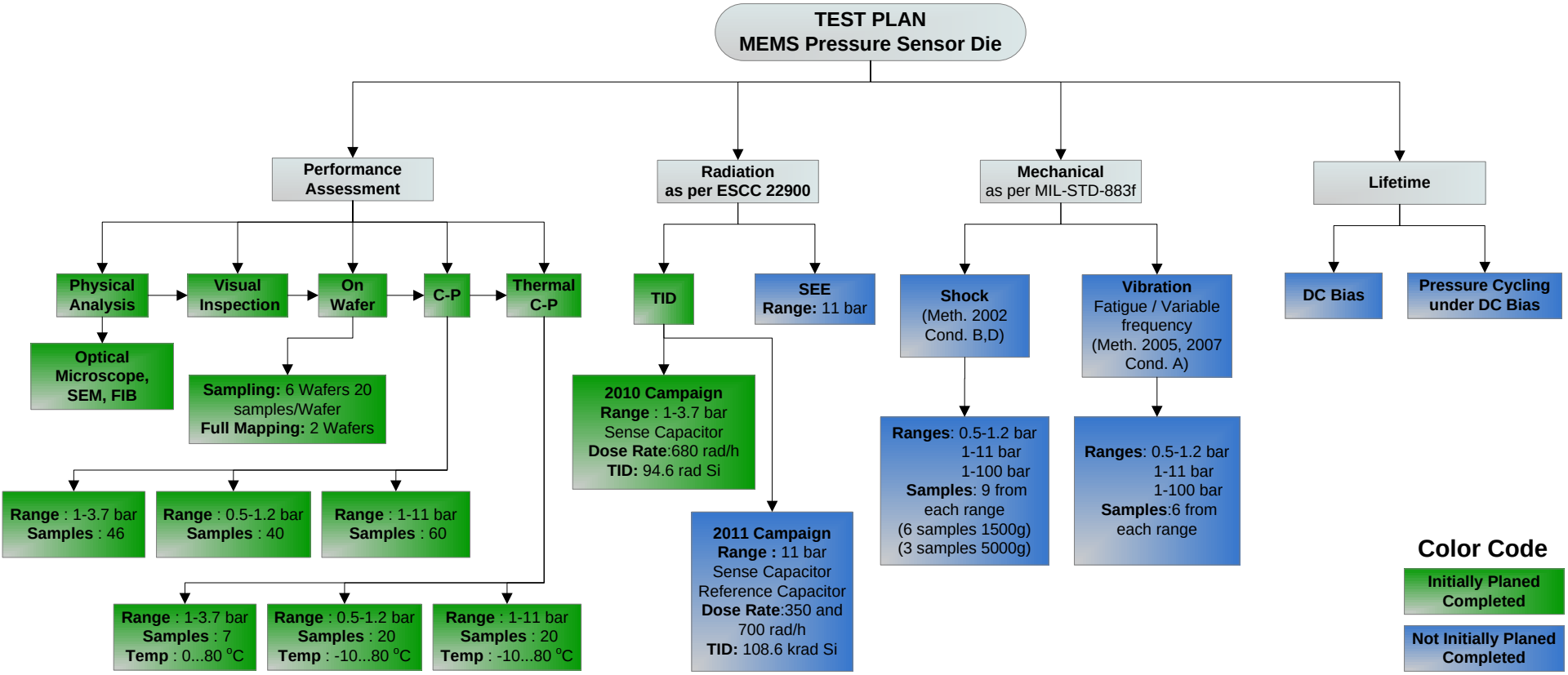




- <u>First generation of ASIC (2003-2007)</u>
  - 0.35um CMOS
- <u>Second generation of ASIC (2007-…)</u>
  0.18um CMOS
- Family of ASIC for Capacitive Sensors (TH108C, TH109C, TH110, TH111, TH112)



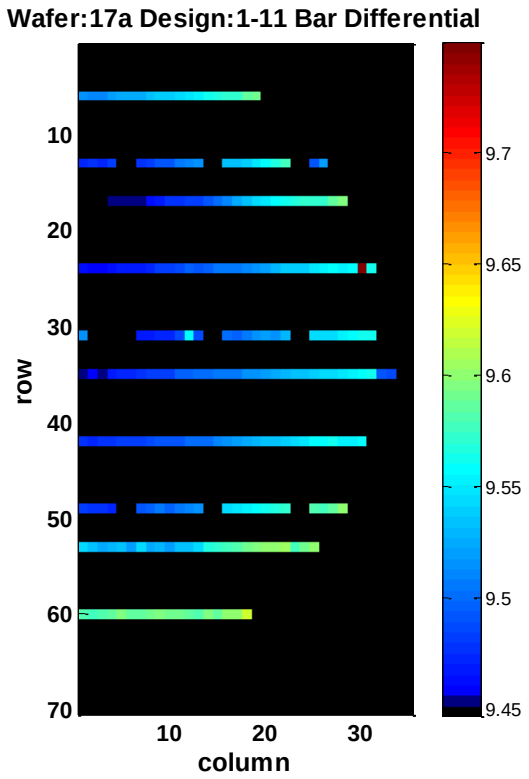
Performance Assessment
MEMS Pressure Sensor Die



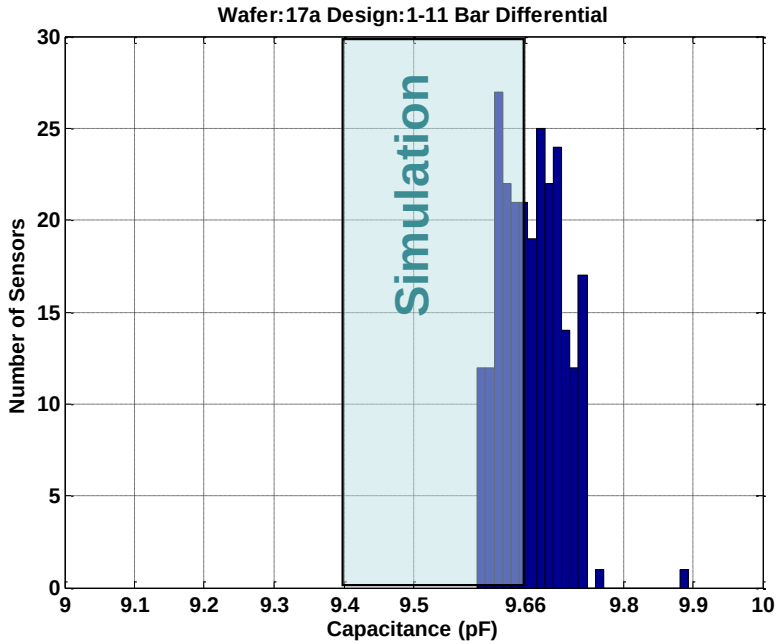
MEMS Performance Assessment On Wafer Measurements

Sensor: 1-11 Bar Differential

Wafer Mapping

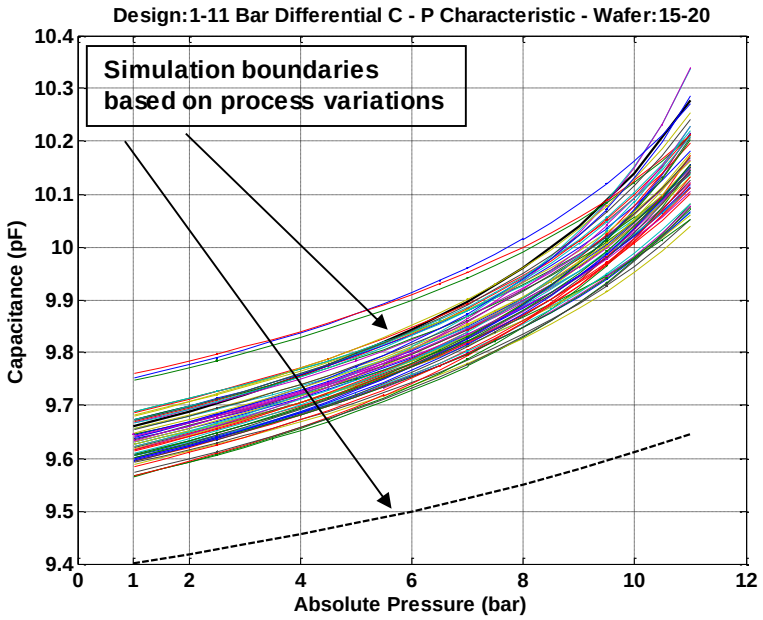


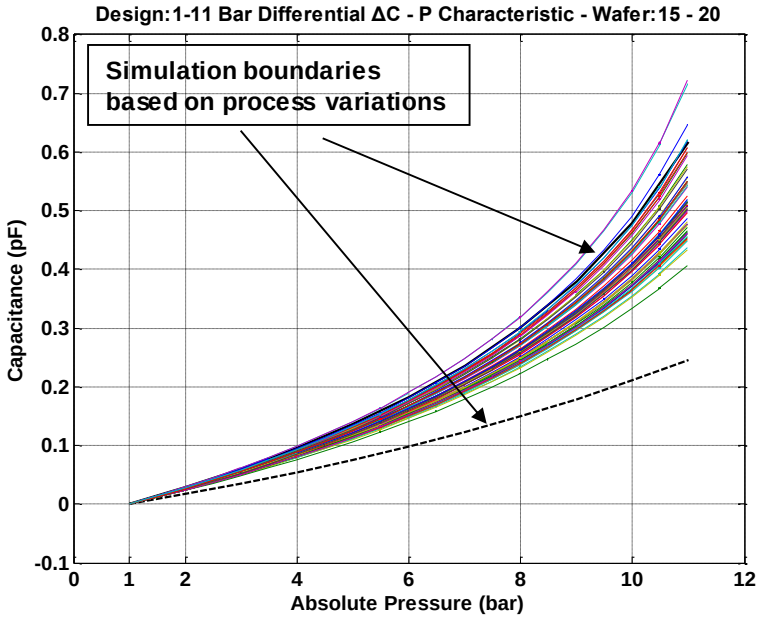
C at Patm histogram



MEMS Performance Assessment
C-P Measurements

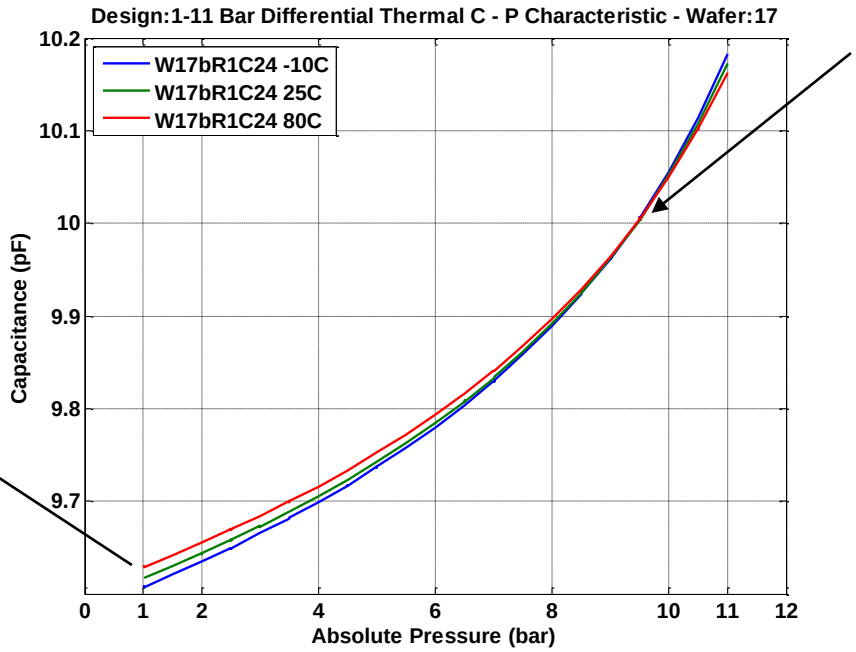
Sensor: 1-11 Bar Differential (60 samples)





MEMS Performance Assessment
Thermal C-P Measurements

Sensor: 1-11 Bar Differential / Temp Range: -10 to 80 ^{0}C (20 samples)



Typical ΔCo ≈ 20 fF (4.2 % FS max)

Sensitivity Drop (7.6 % FS max)

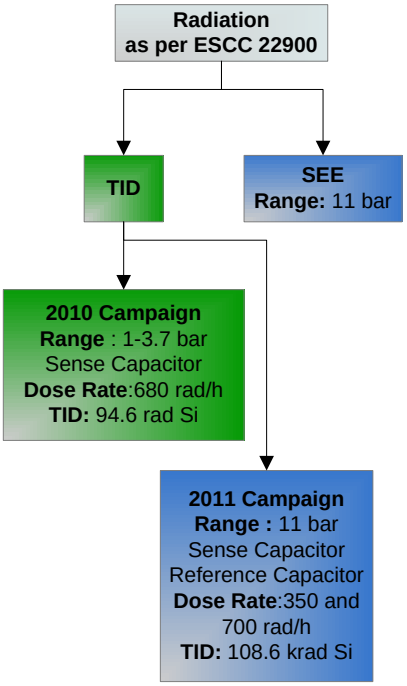
Temperature related offset drifts in Csense are partly compensated with a reference capacitor using differential electronics architecture

MEMS Performance Assessment
Overview of Simulated vs Measured results

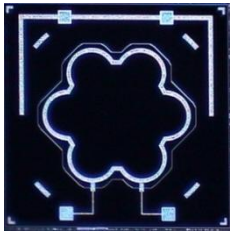
- **Good Wafer to Wafer repeatability**
- **>90% measured versus simulated performance of ΔC**
- **<4% error in Cos measured versus simulated value**

Parameter	Pressure Sensor
	1-11 Bar Dual
Cos prediction accuracy	74%
CFSS prediction accuracy	100%
Error of Sim vs Meas Cos (fF)	< 100
Error of Sim vs Meas Cos (% Cos)	<1%

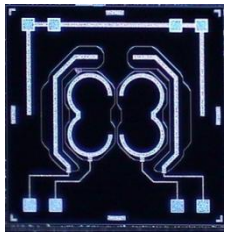
MEMS Performance Assessment Radiation (TID / SEE) - Outcome



3.7 Bar Sensor (TID 2010)



11 Bar Sensor (TID 2011)



- TID Test method: Remote Testing (C – P characteristic before and after each irradiation step)
- All dies remained functional (12 / 6 samples)
- Radiation effect is mainly observed as a negative offset in sensor's sense and reference capacitance
- No change in sensitivity
- Reference capacitor can compensate for ~ 50-60% of the radiation effect using differential readout electronics

- No Single Event Effects were observed with Kr beam @ LET=31 MeVcm^2/mg

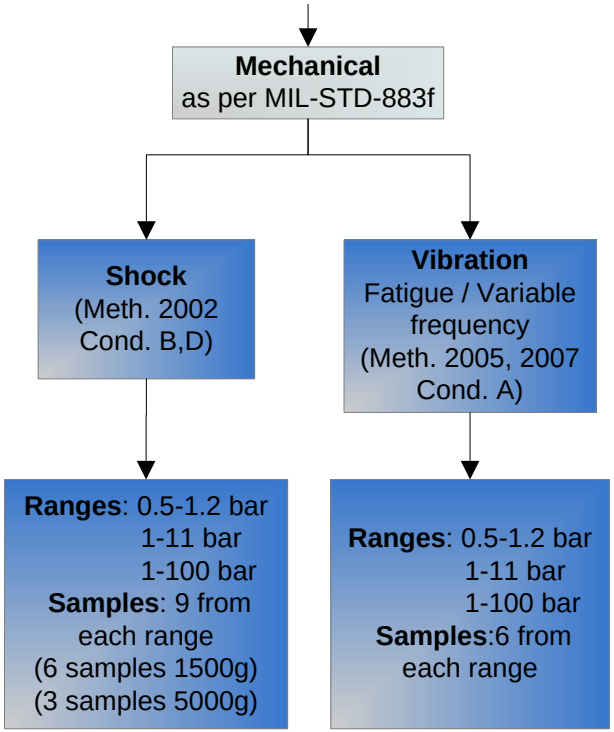
MEMS Performance Assessment Mechanical (Shock / Vibration)

Device under Test

Bare silicon Capacitive Pressure Sensor Dies

Purpose

- Survivability of the membranes
- Thin film delamination
- Loss of hermeticity in vacuum sealed cavity (wafer bonding failure)
- Die fracture



Test Outcome

- Optical inspection, optical profilometry and electrical testing (offset capacitance) revealed no damage or malfunction

MEMS Performance Assessment Lifetime

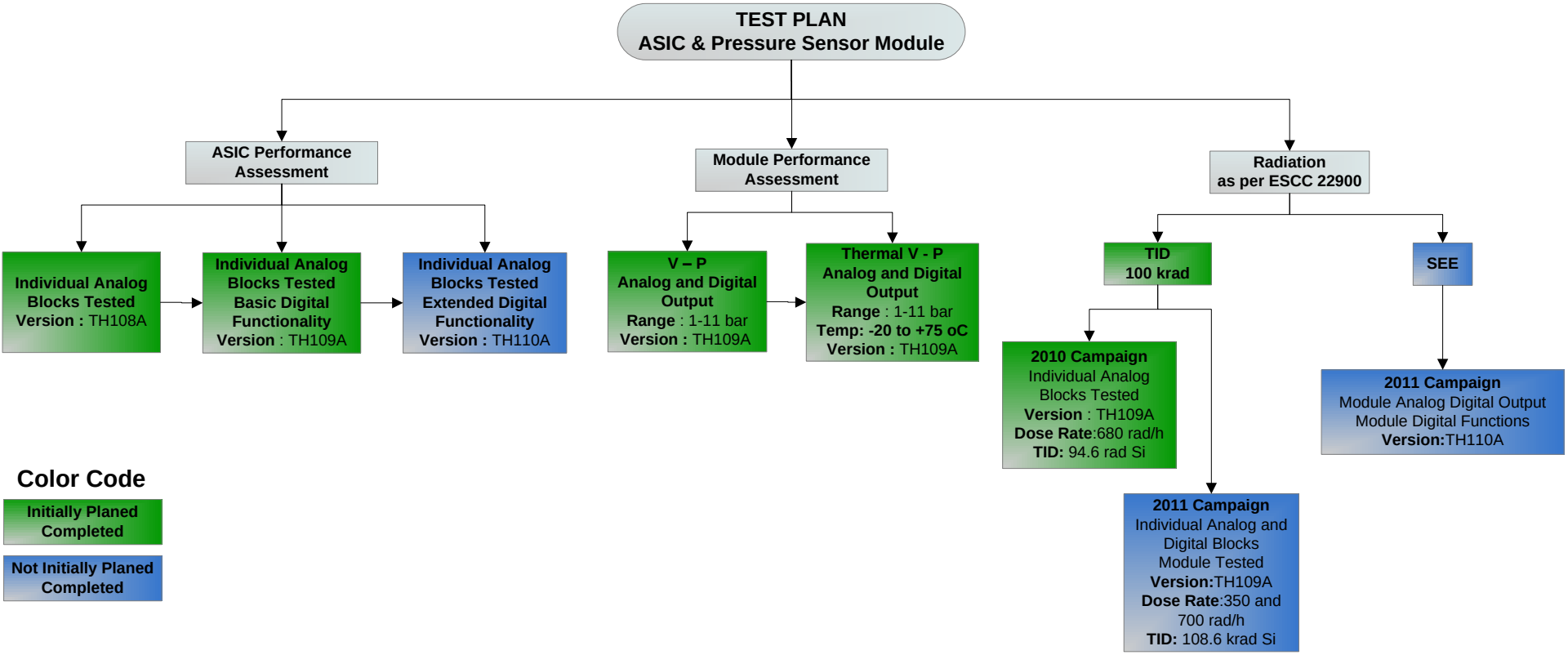
Device under Test
Bare silicon Capacitive Pressure Sensor Dies

Purpose
• Explore possible charge trapping on sensor dielectrics during normal and touch-mode operation

Test 1 – DC Bias under normal operation (3.7 bar sensor)
• Detect sensor C – P output characteristic change after applying 10 V Bias for 120h (normally 1.65 V is applied by the ASIC)
• Outcome: No change detected

Test 2 – DC Bias under cycling touch mode operation (1.2 bar sensor)
• Detect sensor C – V output characteristic change after applying 1.65 and 3.3 V Bias for up to 19.000 cycles of overpressure (2x)
• Outcome: No change detected

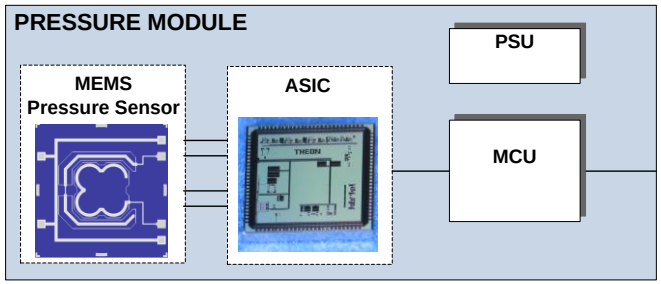
Performance Assessment
ASIC and Pressure Module



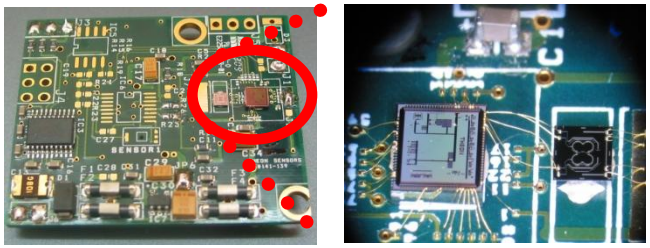
Color Code

- Initially Planed Completed
- Not Initially Planed Completed

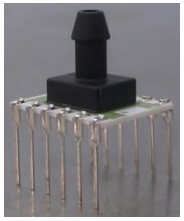
Module Performance Assessment



Prototype

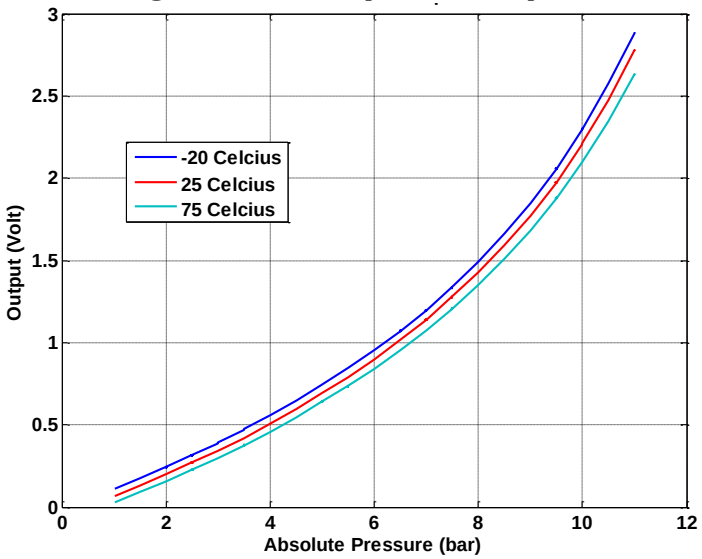


Industrial Prototype



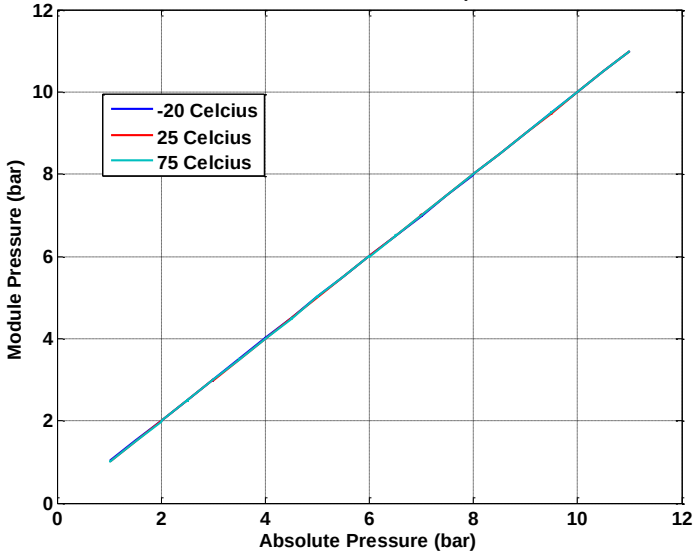
Pressure Range: 1 - 11 bar / Temperature Range: -20ºC to +75ºC

Analog V - P Output - Unprocessed



Digital Calibration
Temp Compensation

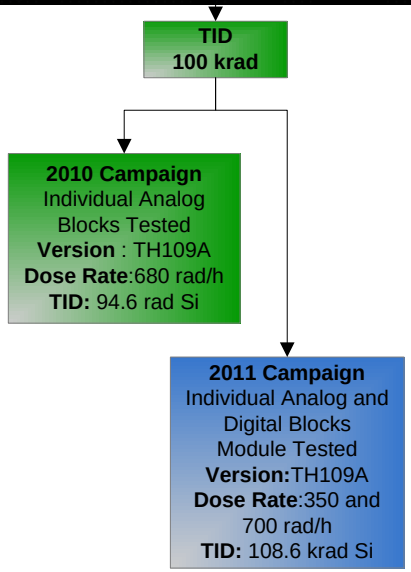
Calibrated/Compensated P Output



Resolution: < 0.05 % FS

Total Error: < 0.5 % FS (including repeatability, hysteresis, linearity, thermal)

ASIC and Module Performance Assessment Radiation (TID)



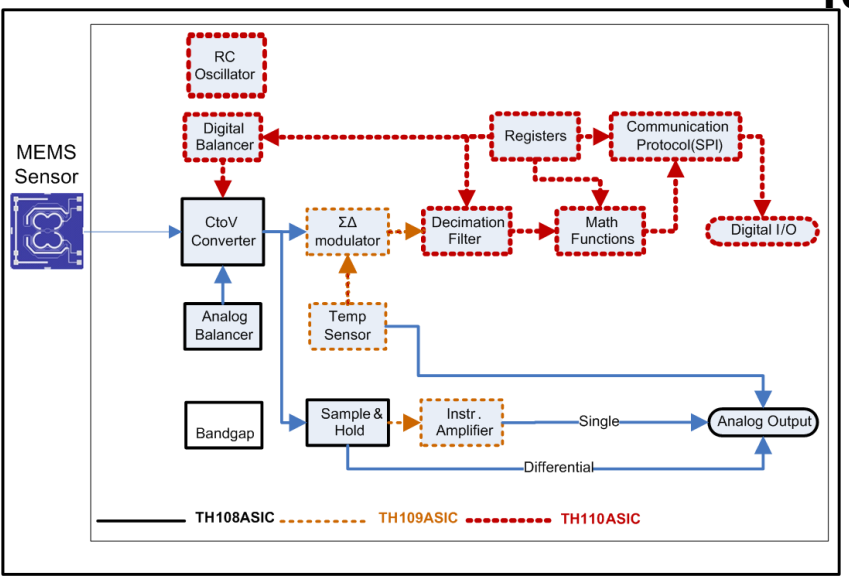
2010 and 2011 TID Campaign at ESTEC

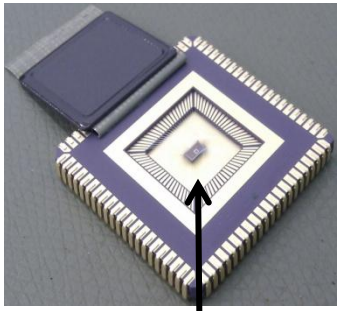
ASIC:

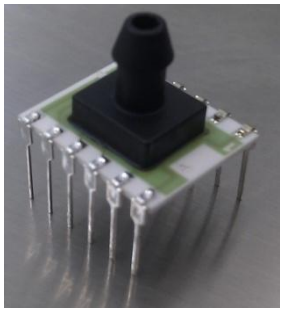
- Bandgap voltage reference (2010, 2011)
- Temperature sensor (2010, 2011)
- Buffer (2010)
- Instrumentation amplifier (2010)
- ΣΔ modulator (2011)

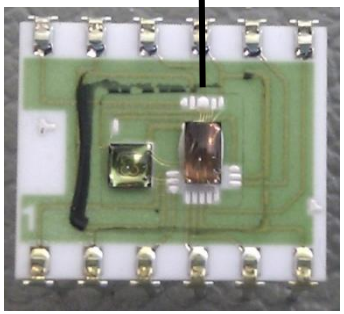
Pressure Module

- Analogue Pressure Output
- Temp Sensor (in situ)









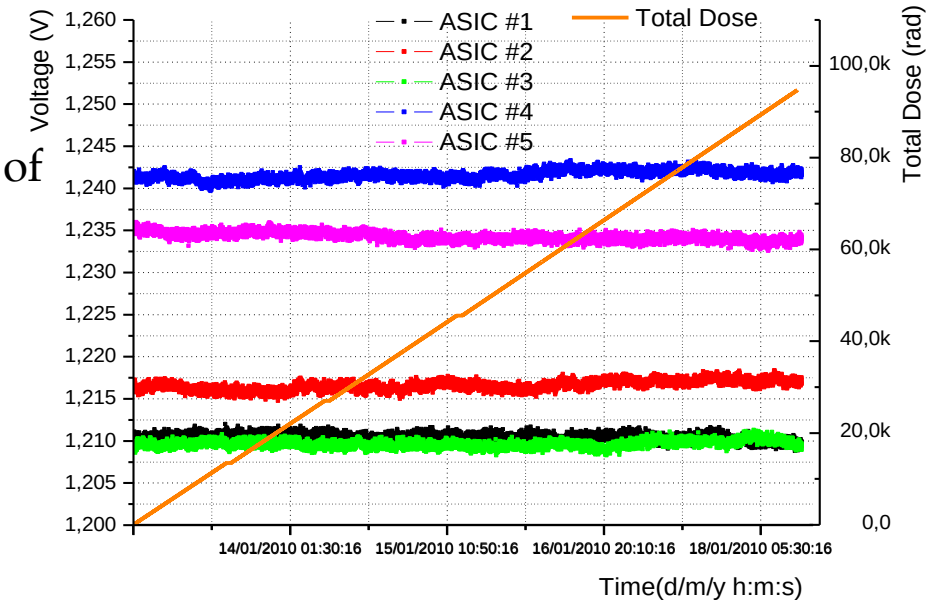
ASIC Performance Assessment Radiation (TID)

1. **TID campaigns**
   - **Irradiation Facilities : ESA / ESTEC**
   - **Source : ^{60}Co (gamma)**
   - **Dose rate: ~680 Rad(Si)/h- ~ 360 Rad(Si)/h**
   - **Total dose : up to 95Krad (Si)- up to 110Krad (Si)**

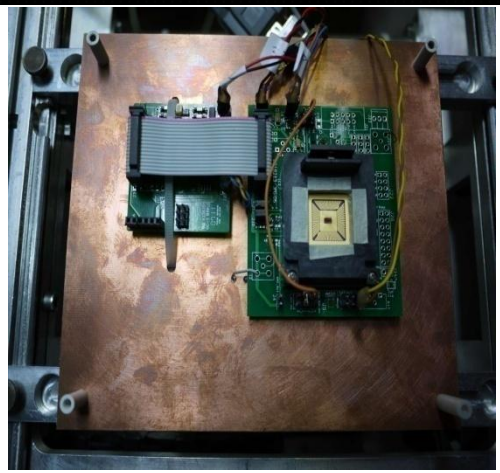
Outcome :

- All ASIC's remained functional after 6 days of continuous operation up to 110Krad
- No drifts were reported in the output of all basic building blocks
- No significant change in power consumption observed
- All modules remained functional
- Further verification is needed in system level

Bandgap Reference*(During irradiation)*



ASIC Performance Assessment Radiation (TID)



•*3 Radiation campaigns were implemented with THEON ASIC's*

1. **TH110 – SEL/SEU campaign**
   - **Irradiation Facilities : UCL, BELGIUM**
   - **High LET-High penetration cocktails**
   - **Flux: 3 x 10^3 to 6 x 10^3 particles/cm^2/s**

Outcome :

- ASIC's were sensitive to SEL with a LET threshold around 10 MeVcm^2/mg
- SEL was not destructive and the ASIC's recovered full functionality after a power cycle
- ASIC's were sensitive to SEU with threshold around 3.6 MeVcm^2/mg
- SEU was not destructive and the ASIC's recovered after a reset operation

Identification of Industrial Partner

- **Thales Alenia Space (TAS)** was identified as a potential industrial partner and joined the activity
- Development of a space qualified family of MEMS pressure transducers for **Satellite Propulsion Systems**
- Preliminary design of new MEMS capacitive pressure sensors was done
- Preliminary design of the complete transducer including packaging
- Development plan of the family of MEMS pressure transducers

Performance Demonstration of THEON's existing Pressure Modules for Space Applications

Activity started on Feb 2009 and successfully concluded on Sep 2011

Scope and objectives of activity :

- Assessment of THEON's existing pressure sensing technology
- Design of a technology demonstrator for an identified space application

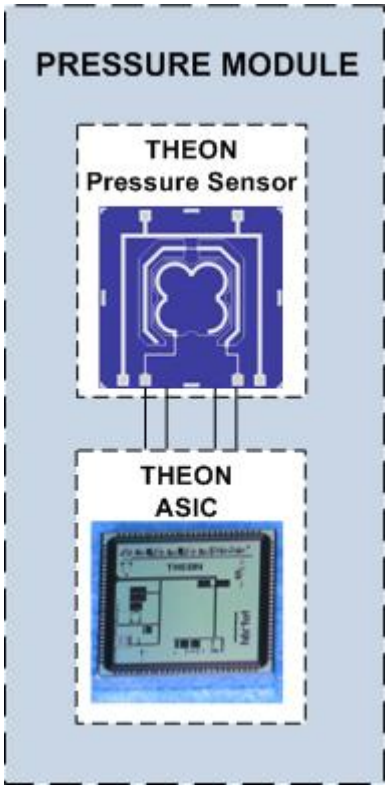
Outcome :

- THEON's pressure sensing technology is capable of serving space applications
- Testing campaign reported very promising results (radiation, vibration,…)
- Identification of Thales Alenia Space as an end user
- Preliminary design of Pressure Sensors based on TAS specifications

THEON and TAS will develop a "Space Qualified Family of MEMS Pressure Modules for Satellite Applications" under a new ESA activity started within Q3 2012.

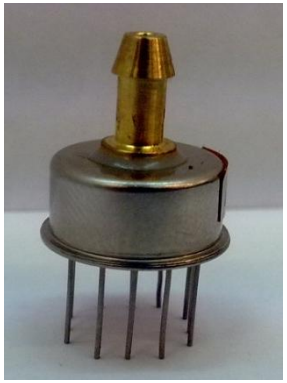
Current Status of THEON pressure sensors

• Architecture

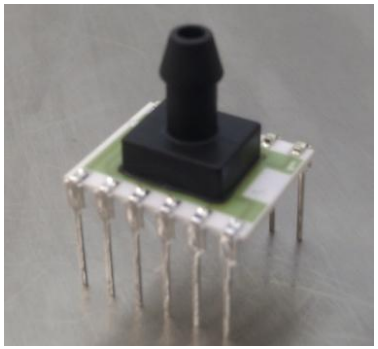


Specifications	
Calibration medium	Gas, Liquids, etc
Pressure range	1.2, 2, 11, 28, 325 bar Custom
Supply Voltage	3.3 , 5 , 12V
Output	Analog, SPI, I2C, Custom
Repeatability	<±0.05%FS
Hysteresis	<±0.05%FS
Total Error	<±0.5%FS
Resolution	16bit
Temperature	-20 °C +80 °C
Size	Custom

• TO package



• DIP package



• Stainless steel package

Thank you!

“Performance Demonstration of THEON’s existing Pressure Modules for Space applications”

MNT Round Table
ESTEC, 17 October 2012