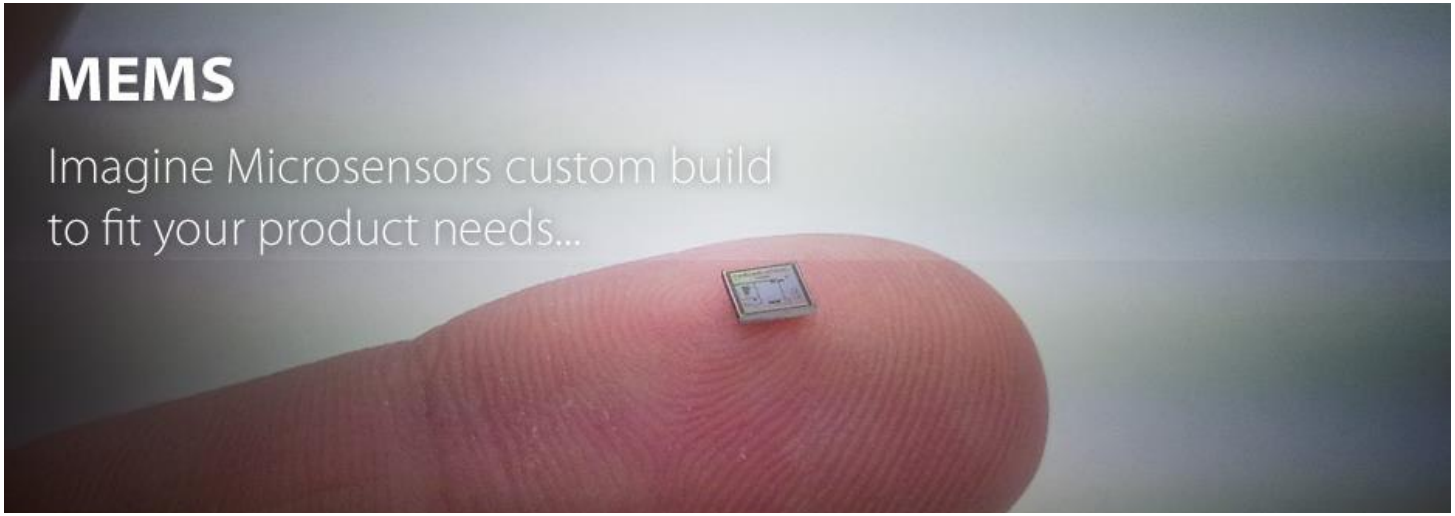


Development of MEMS Space Qualified Pressure Transducers

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

9th MNT ROUND TABLE, 10-13 June 2014

www.theon.com

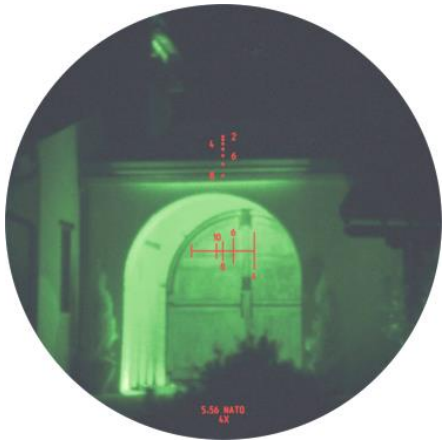
Outline

- ***Company overview***
  - THEON/ESS Profile
  - Overview of technologies/capabilities/products
  - Space related activities
- ***Pressure transducers for space applications***
  - Background & Objective
  - System architecture
  - MEMS pressure sensors
  - Radiation hardened CMOS signal conditioning electronics
  - Pressure component / transducer
  - Status / Next steps
- ***Summary - conclusions***

Company Profile

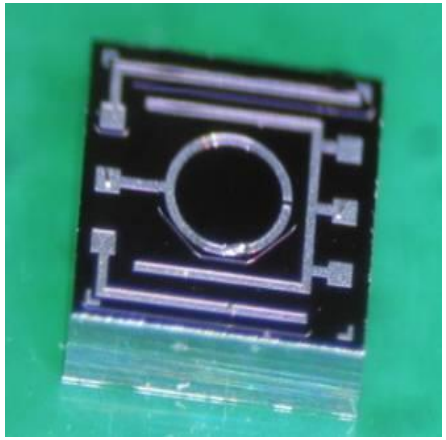
- **Privately owned company established in 1997 and rapidly expanded in the world market**
- **Based in Greece but operating worldwide with offices in UAE and Singapore.**
- **A *high technology* company with advanced design and development capabilities, *flexibility* and *custom made approach***
- **Key Figures (2013): Sales €37 Million**
- **Personnel : ~80 (>50% highly trained engineers)**
- **ISO 9001:2008, NATO security certification**

Company Structure



Electro-Optic Systems

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

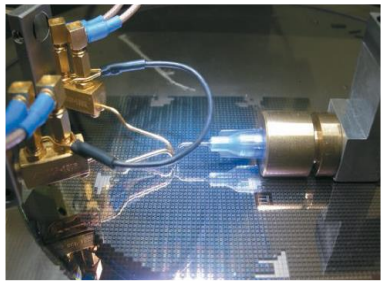


Micro Electronic Mechanical Systems (MEMS)

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

Company Profile

- Privately owned company started operations in 2013- located in Athens
- A global developer and manufacturer of high quality sensors based on ***micro-electronics technologies (MEMS)***
- A ***high technology company*** with advanced design and development capabilities, ***flexibility*** and ***custom made approach***
- Our vision is to deliver ***high quality products*** customized to meet the demanding requirements and conditions of our clients
- Portfolio of Sensors : ***Pressure Sensors***
  Air Flow Sensors
  Accelerometers



Business Model

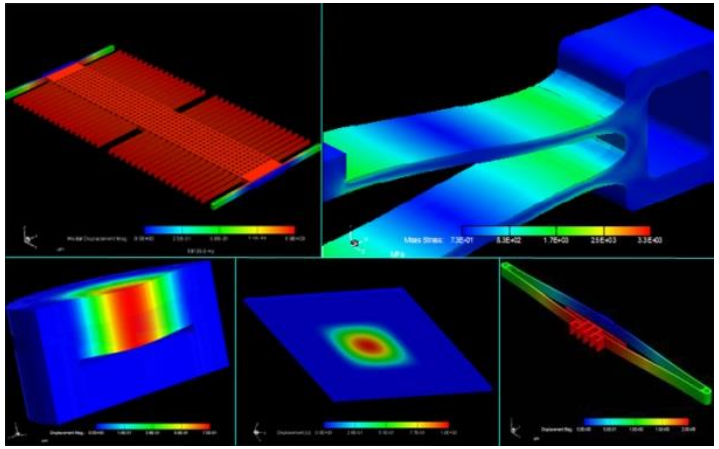
Designed internally by ESS
Fabrication is Outsourced

- MEMS Sensors
- CMOS electronics
- PCB's
- Mechanical packages
- Calibration Algorithms

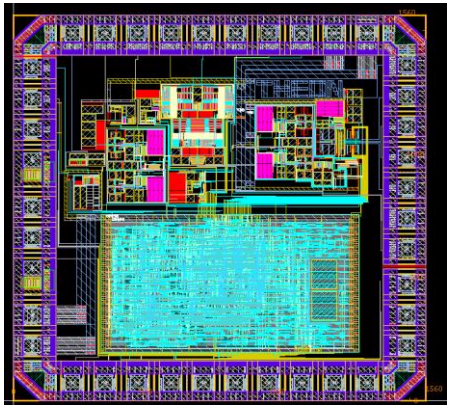
- ***Full control*** and ***ownership*** of all aspects of our products
- ***Fabless model*** gives flexibility and large capacity
- Since 100% of the design is implemented in house, ESS is ***capable*** and ***flexible*** to design, develop and fabricate ***custom made sensing solutions***
- Move fast from concept to prototyping to mass production
- ESS is ***one stop solution*** for sensing systems enabling ***fast time to market***

Design Capabilities

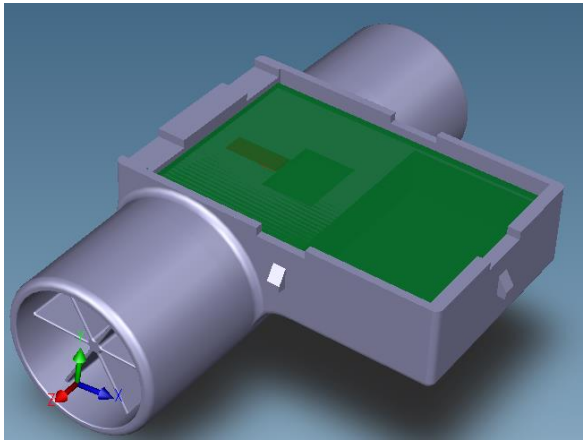
- Design of MEMS sensors



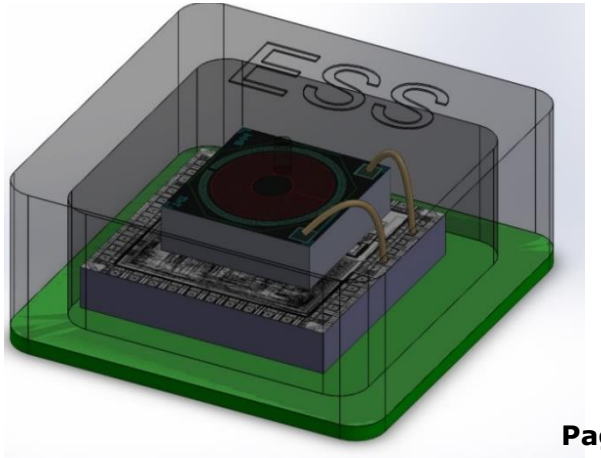
- Design of signal conditioning electronics



- Design of mechanical parts



- Design of packages

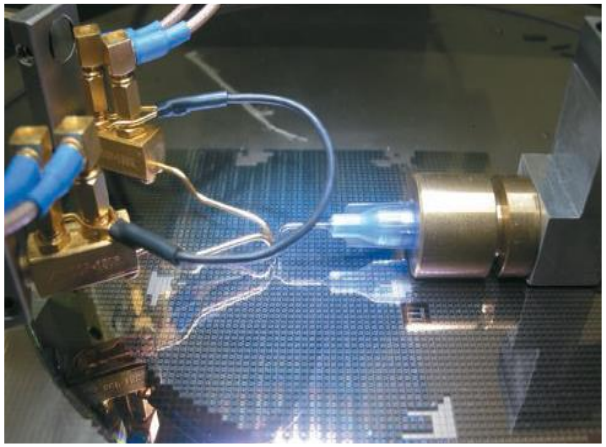


Infrastructure

- Die Bonder

- Wire Bonder

- Probe Station



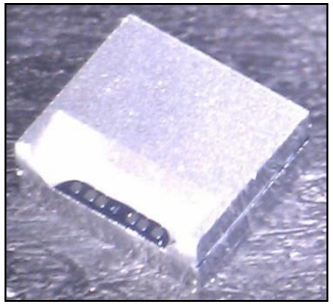
- Climatic Chamber

Products

- Pressure Sensors

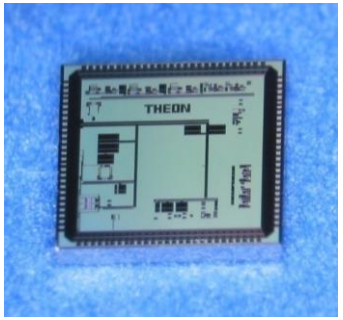


- Accelerometers




- Flow Sensors


- Signal Conditioning Electronics



Applications

- Aerospace applications (Navigation, Propulsion)

- Industrial applications

- Medical applications (pumps, blood pressure, respiration)

- Consumer Goods

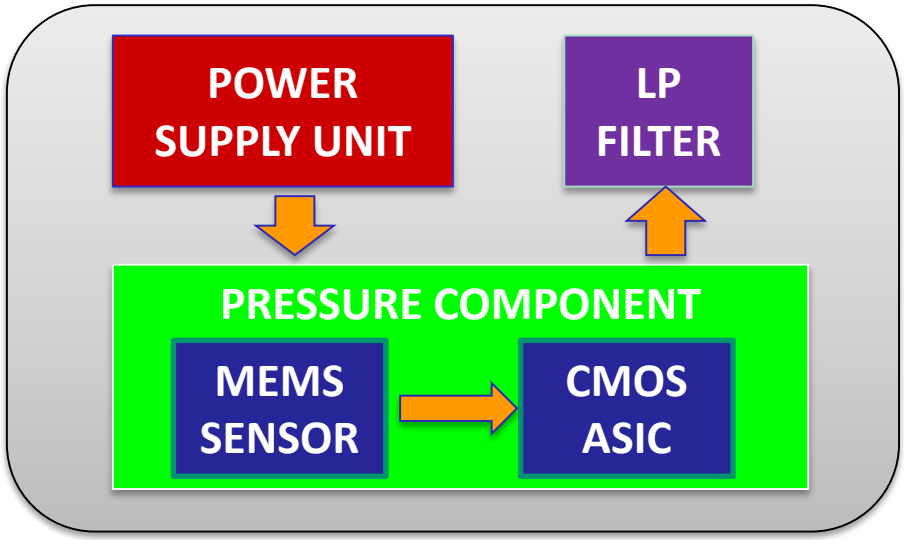
ESA activities* (Overview)

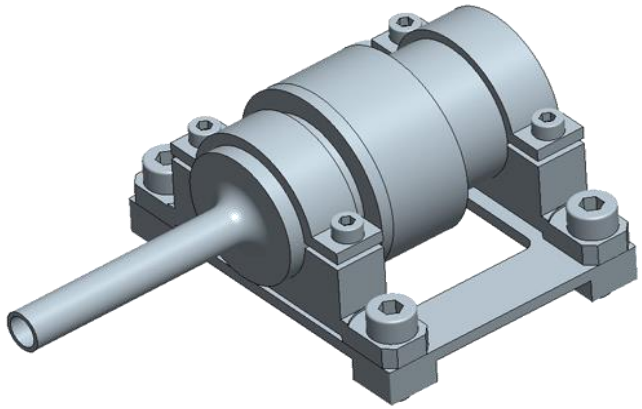
1. *"Feasibility Study for MEMS-SOI Capacitive Accelerometer" (Sep 2007 - Nov 2008)*
2. *"Flight Demonstrator for a MEMS Accelerometer for Launchers" (Sep 2009 - PDR on Dec 2010)*
3. *"Accelerometer Re-direction study" (Nov 2011 - Dec 2013)*
4. *"Accelerometer component to TRL5" (Jan 2013 - …)*
5. *"Performance Demonstration of THEON's existing Pressure Modules for Space applications" (Feb 2009 - Sep 2011)*
6. *"Space Qualified Family of MEMS Pressure Modules for Satellite Applications" (Sep 2012 - …)*
7. *"Connectivity and Packaging of Systems of Microsystems" (Jan 2013 - …)*

* These activities are implemented initially through THEON and nowadays trough ESS

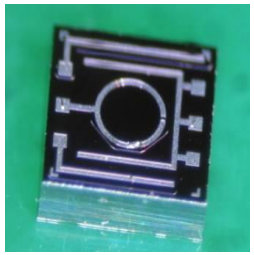
Objective

- THEON (ESS) is the contractor and THALES ALENIA SPACE the end user
- Develop a family of ITAR free Pressure Transducers for measuring the remaining propellant medium in the propulsion subsystem
- Ranges: 7bara, 26bara, 150bara, 325bara

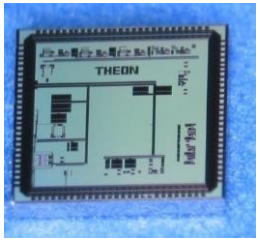




Pressure Transducer



MEMS



CMOS

PRESSURE COMPONENT

MEMS Pressure Sensor Technology

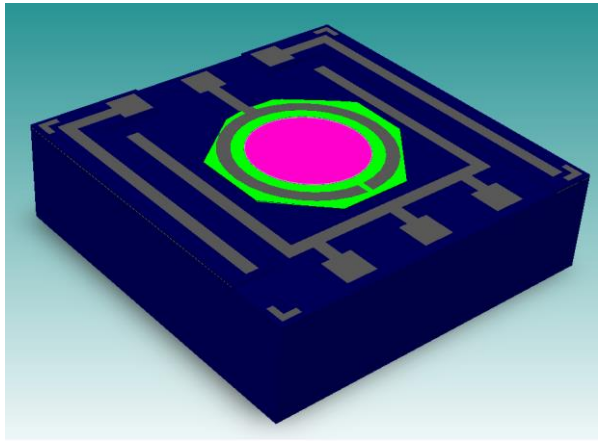
Principle of Operation

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

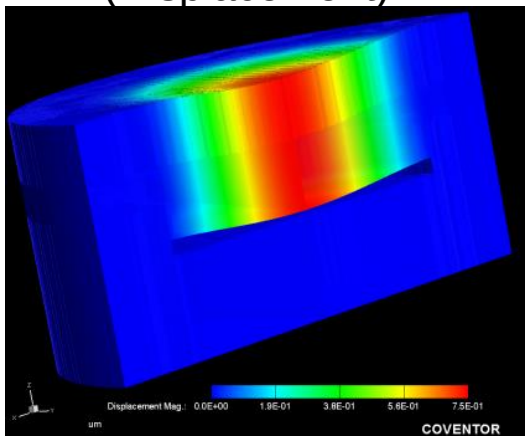
Features of Microfabrication Process

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

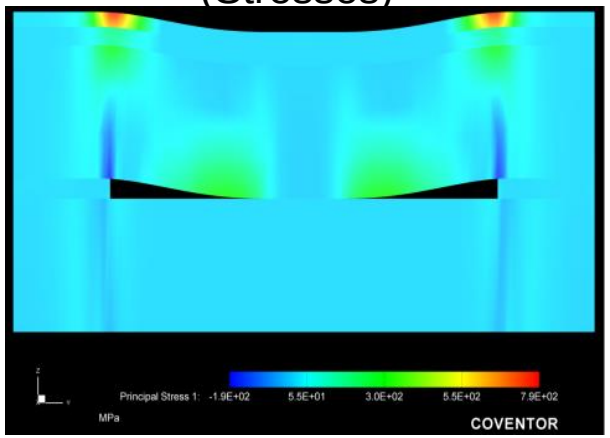
3D model



Simulation result (Displacement)



Simulation result (Stresses)

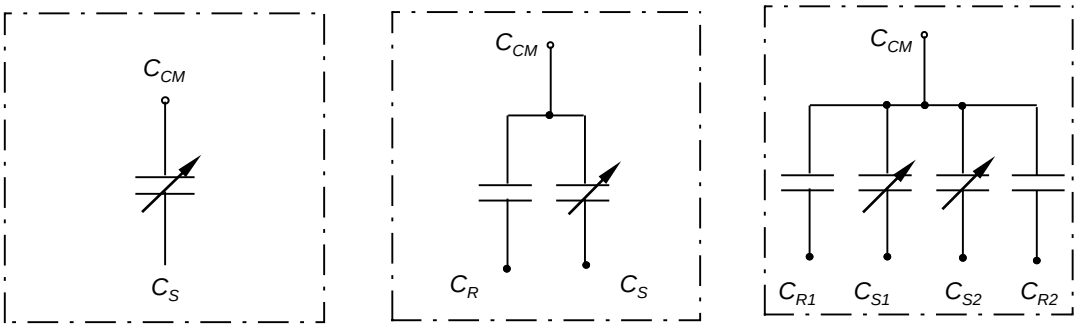


MEMS Pressure Sensor Technology

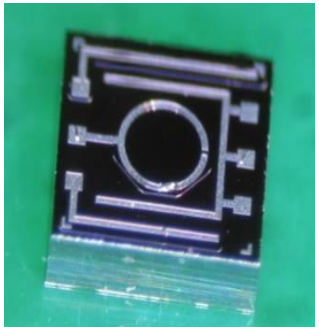
Key Technology Features

- Small Size (2 mm X 2 mm) – Less than 1mm upon request
- Low Power Consumption (Intrinsic Properties / Principle of Operation)
- Low Sensitivity to Environmental Variations (Intrinsic Properties / Die materials)
- Excellent long term stability

- Architecture : Single / Single with Reference / Dual with Reference configurations



- Pressure Ranges
  - Low Pressure : 0-2bara
  - Medium Pressure :0-15bara, 0-35bara
  - High Pressure : 0-150bara, 0-350bara, 0-1000bara



- ***Differential pressure sensors under development : 10mbar, 100mbar, 2bar, 15bar, 35bar***

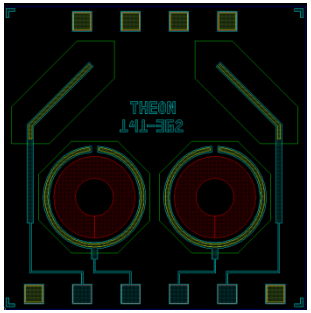
MEMS Pressure Dies

- ***Activity is towards CDR***

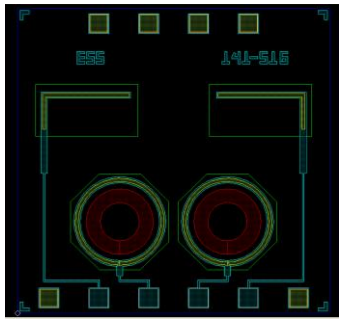
THEON has designed and made an early prototype fabrication of the following MEMS pressure sensors taking into consideration the applications' pressure ranges:

DESIGN	*RANGE COVERED*	*MEMS RANGE*
1st Design	: 2.5 – 7bara	0 – 11 bara
2nd Design	: 5.5 – 25.8bara	0 – 30 bara
3rd Design	: 3 – 150bara	0 - 150 bara
4th Design	: 30 – 310bar	0 – 325 bara

1st Design
141-365
ESCP2-0011.0



2nd Design
141-362
ESCP2-0028.0



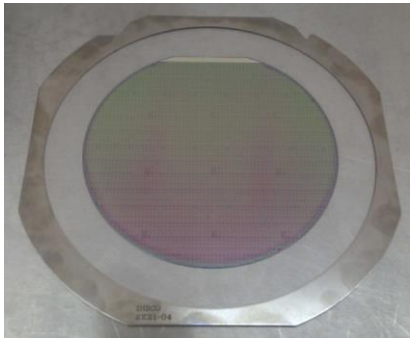
3rd Design
141-516
ESCP2-0150.0

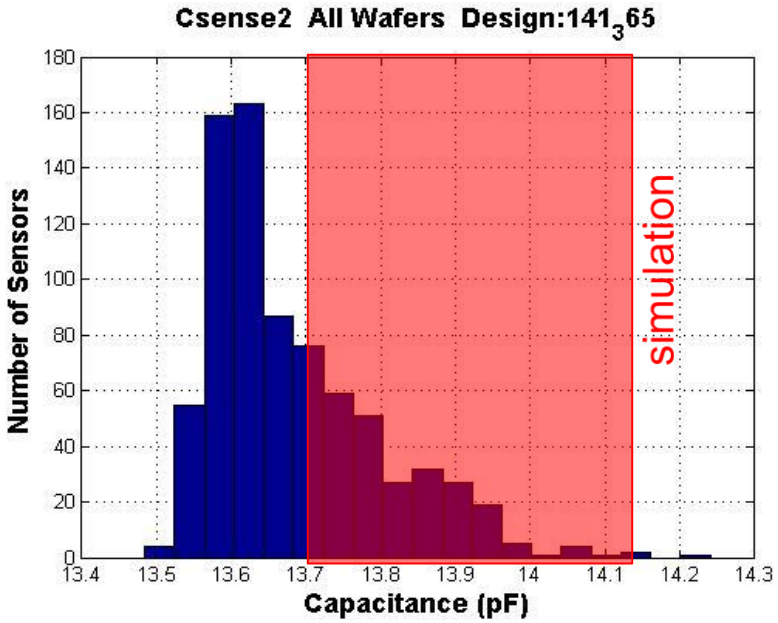
4th Design
141-363
ESCP2-0325.0

11bar Pressure Sensor

ESCP2-0011.0-ADRR

- Absolute capacitive pressure sensor with range up to 11bar
- Size: 2mm (L) x 2mm (W) x 0.4mm (H)
- Architecture with 2 sense and 2 reference capacitors
- Full wafer mapping at 0.5bar (13.2pF ± 0.2pF)

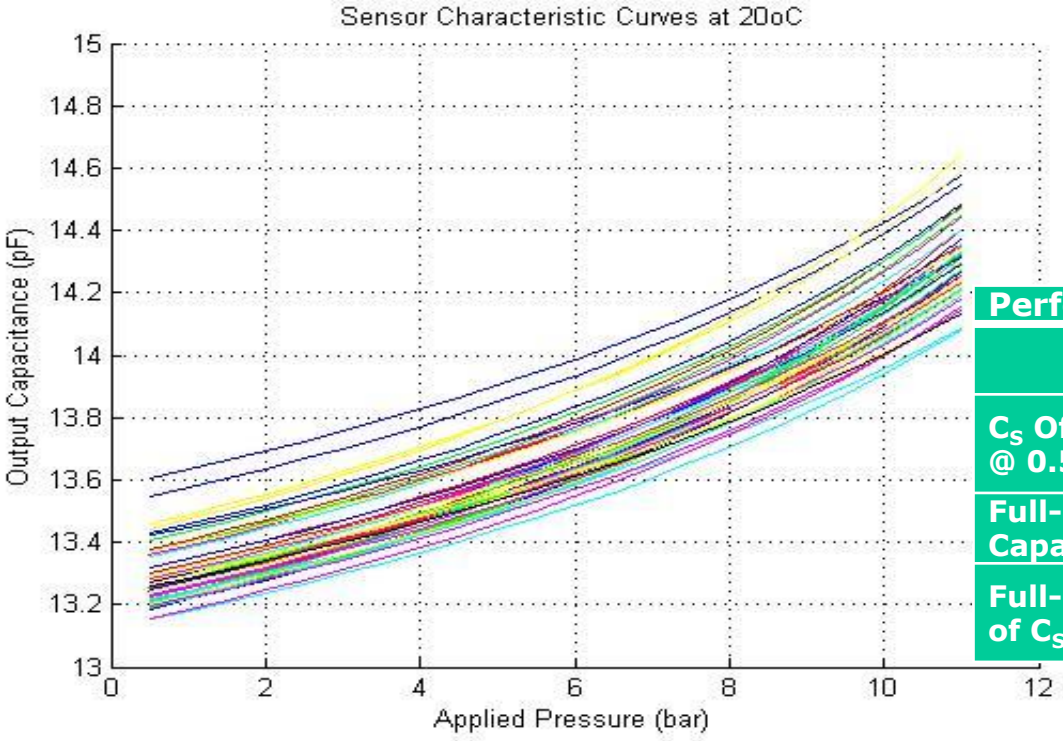


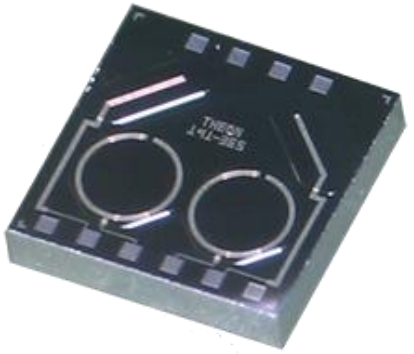


11bar Pressure Sensor

ESCP2-0011.0-ADRR

- Capacitance change versus pressure @ 20°C



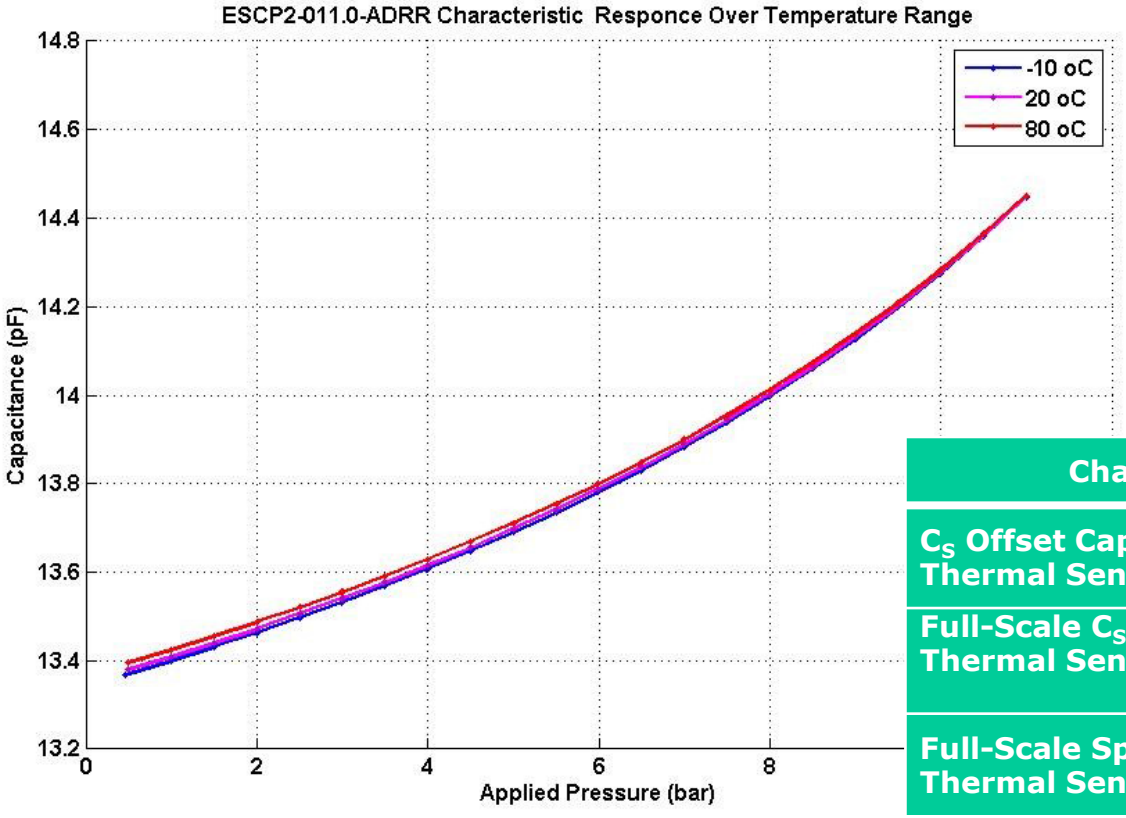


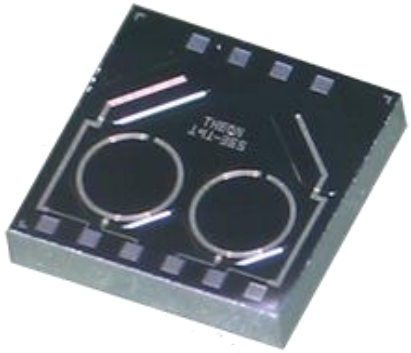
Performance Characteristics				
Characeristic	Min	Typical	Max	Units
C_S Offset Capacitance @ 0.5 bar & 20°C	13.1	13.2	13.4	pF
Full-Scale (FS) C_S Capacitance @ 11 bar	14.1	14.2	14.4	pF
Full-Scale Span (FSS) of C_S Capacitance	0.9	1.0	1.1	pF

11bar Pressure Sensor

ESCP2-0011.0-ADRR

- Capacitance change versus pressure (Thermal characteristic)



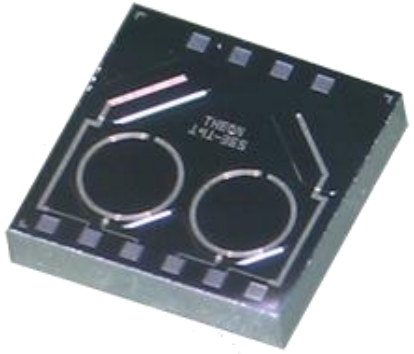


Characteristic	Typical	Units
C_S Offset Capacitance Thermal Sensitivity	-0.272	fF/°C
Full-Scale C_S Capacitance Thermal Sensitivity	-0.064	fF/°C
Full-Scale Span C_S Capacitance Thermal Sensitivity	-0.336	fF/°C

11bar Pressure Sensor

ESCP2-0011.0-ADRR

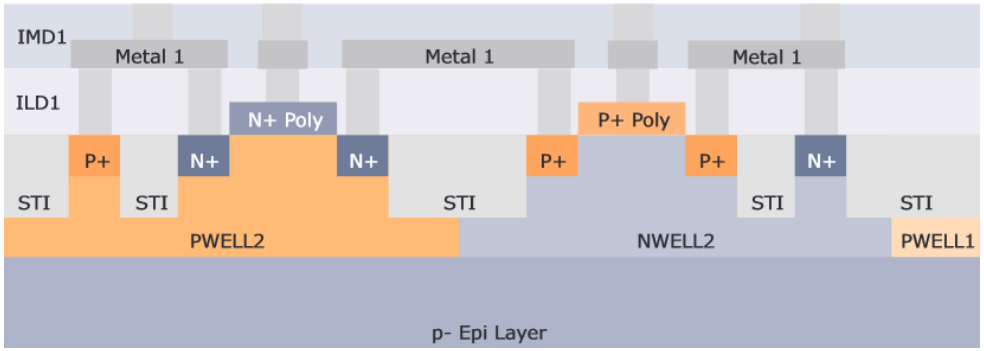
Performance Characteristics				
Characteristic	Min	Typical	Max	Units
C_S Offset Capacitance @ 0.5 bar & 20°C	13.1	13.2	13.4	pF
Full-Scale (FS) C_S Capacitance	14.1	14.2	14.4	pF
Full-Scale Span (FSS) of C_S Capacitance	0.9	1.0	1.1	pF
C_R	13.5	14.1	14.9	pF
Non-Linearity @ 20°C	8.8%	10.5%	12.2%	FS
Hysteresis @ 20°C		< 0.005%		FS
Repeatability @ 20°C		< 0.05%		FS



CMOS Fabrication Technology

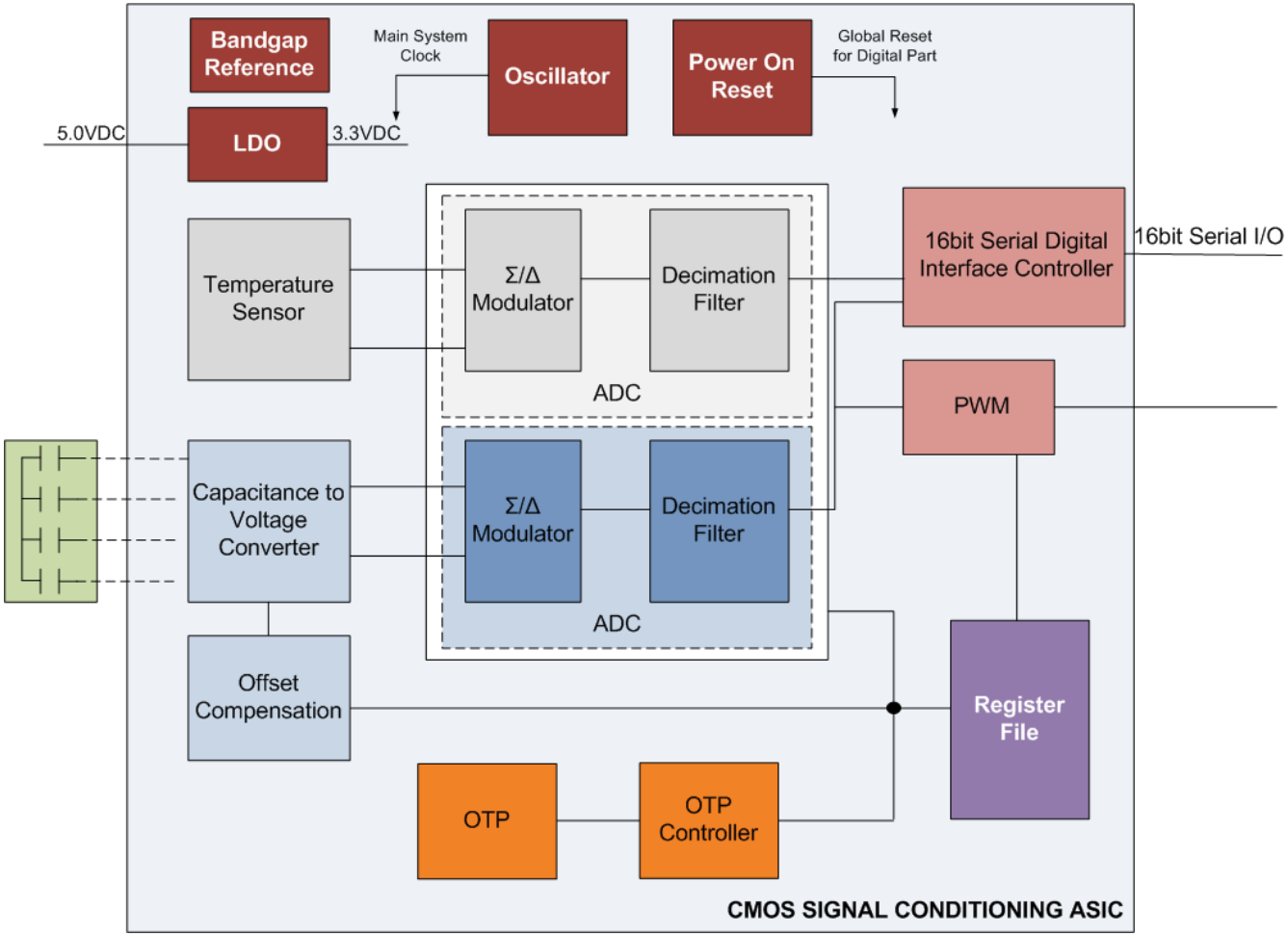
Fabrication Technology: XFAB XH018 (0.18µm CMOS)

- European foundry - ITAR free
- High Voltage devices



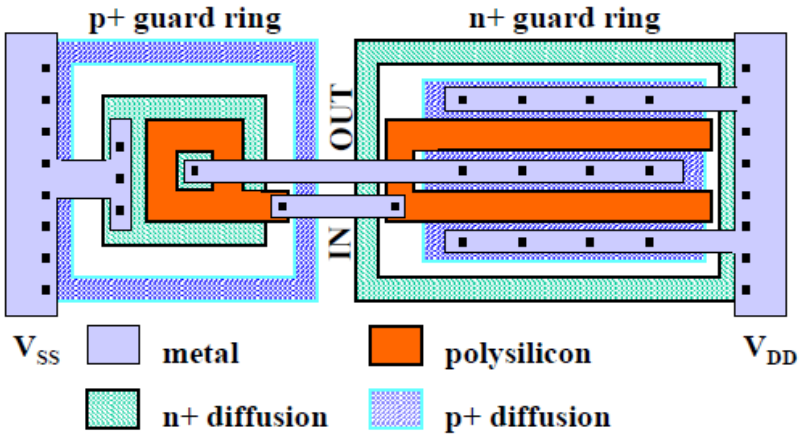
- High performance characteristics
  Selected after performance evaluation of different technologies
- Non-volatile memory options (OTP)
  Enables the use of One Time Programmable memory for storing the trimming configuration and coefficients
- Radiation hardening of circuits by design and layout techniques
  Rad hard technologies not commercially available or ITAR restricted

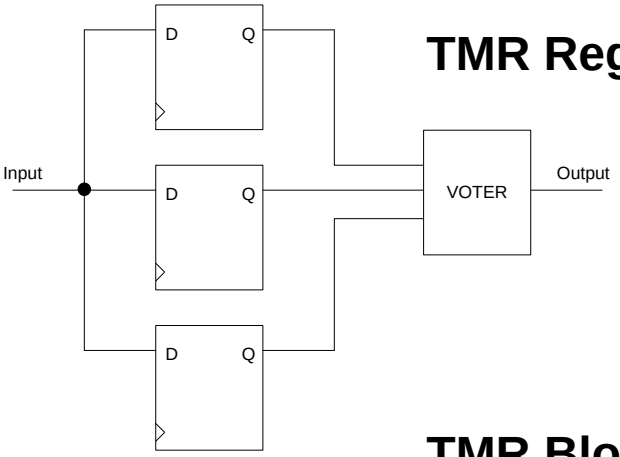
- ***Radiation hardened ASIC (Digital & Analog Output available)***

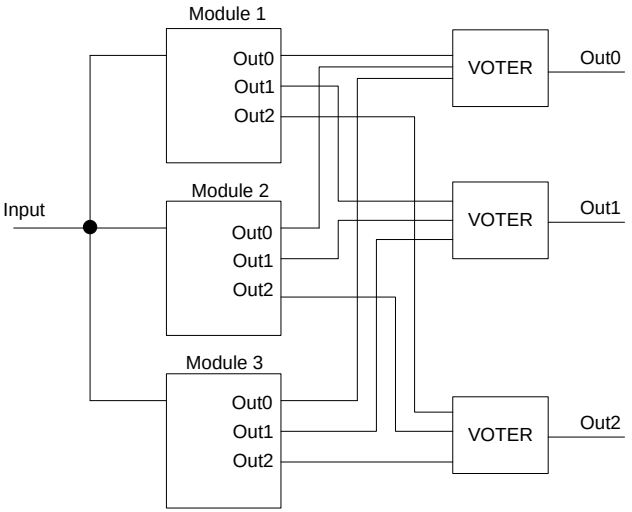


Radiation Hardening

- ***Radiation hardened ASIC (Digital & Analog Output available)***

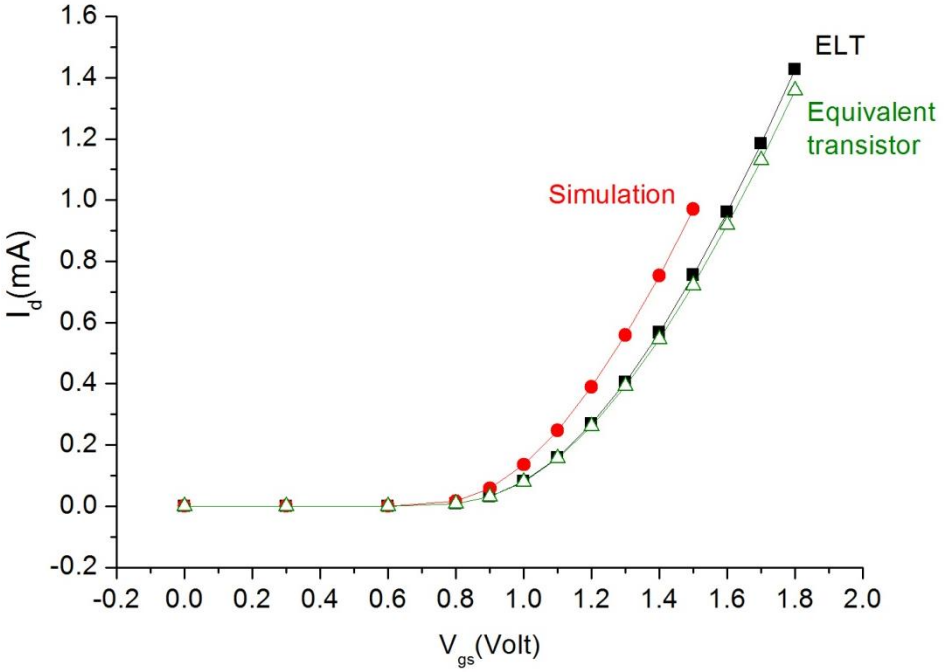


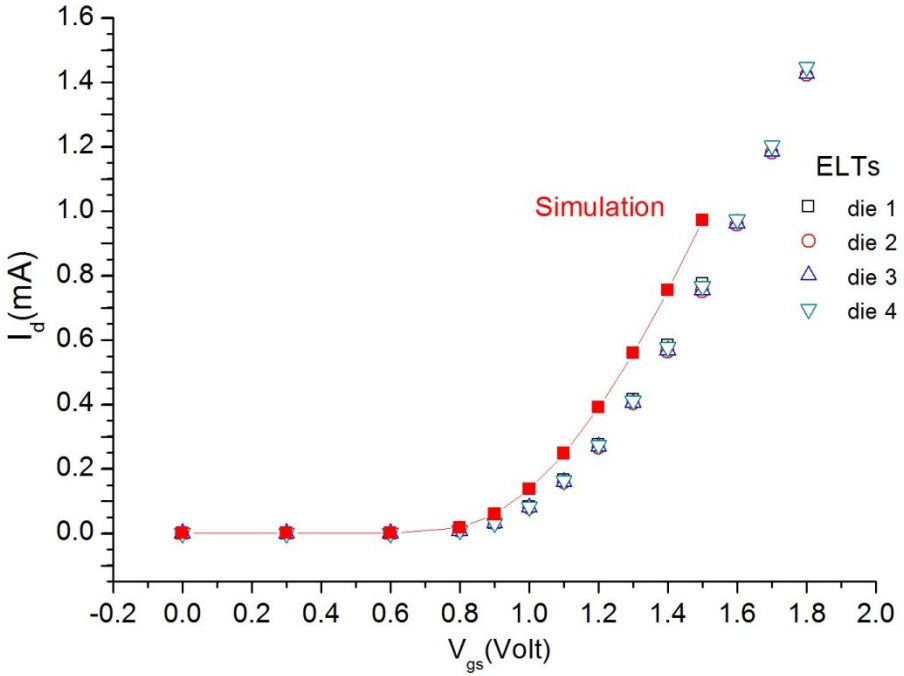




- Implementation of NMOS devices in enclosed geometry
- P+ guard ring around NMOS devices
- N+ guard ring around PMOS devices
- Triple Module Redundancy (TMR) technique
- Power Domain Separation

ELTs vs Regular Devices





- Specifically developed model for the simulation of enclosed transistors
- Measurement of enclosed transistor I-V and comparison with regular transistor. Highly satisfying correlation (worst case 15% difference between ELT – regular)
- Minimal effects due to process variations

Pressure Component

- Fabrication out of Titanium
- Co-integration of the MEMS pressure sensor die and the CMOS signal conditioning electronics
- Two types of pressure components will be fabricated

    1. High pressure component (150bara & 325bara)
    2. Low pressure pressure component (7bara & 26bara)

- Digital Pressure Output (non calibrated)
- Digital Temperature Output
- Analog Pressure Output (non calibrated)

- Pressure barriers 2

Pressure Transducer

- All Titanium Housing

- Two types of pressure transducers will be fabricated

  1. High pressure component (150bara & 325bara)
  2. Low pressure pressure component (7bara & 26bara)

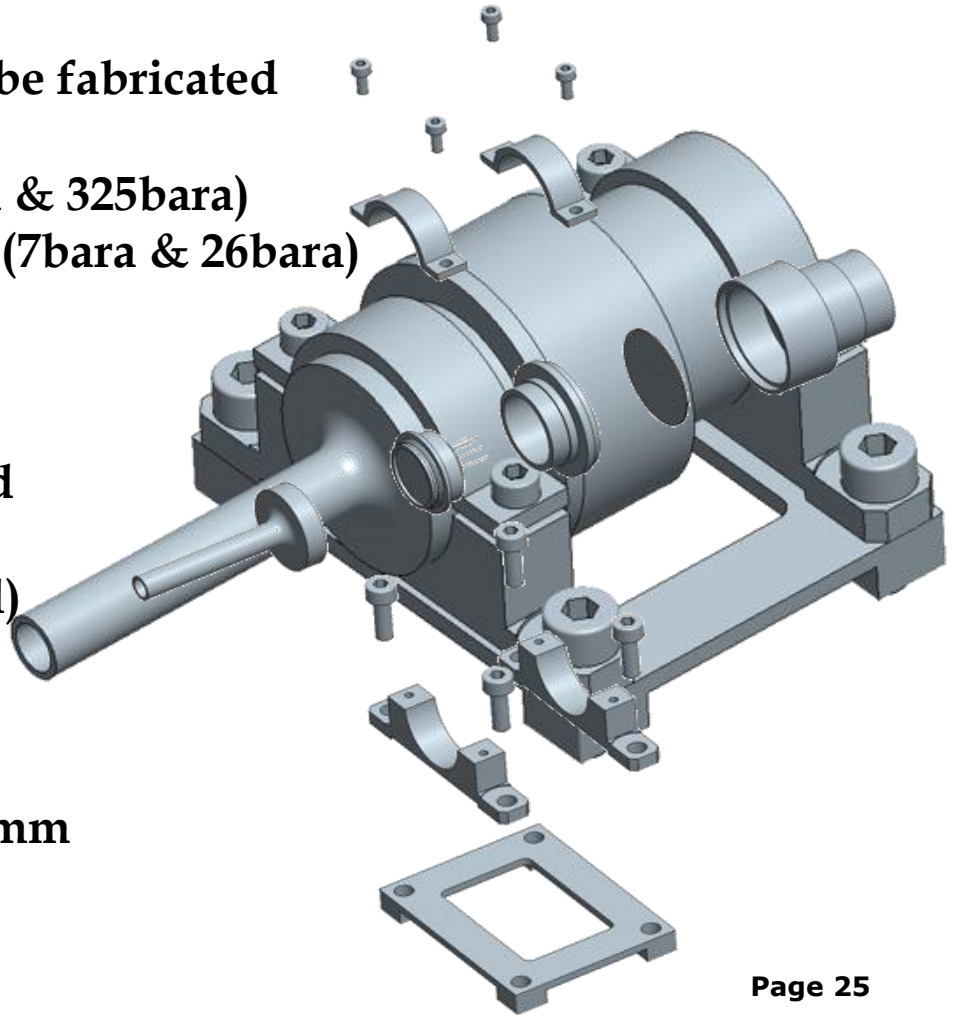
- PSU will be integrated

- Additional thermistor will be integrated

- Analog Pressure Output (non calibrated)

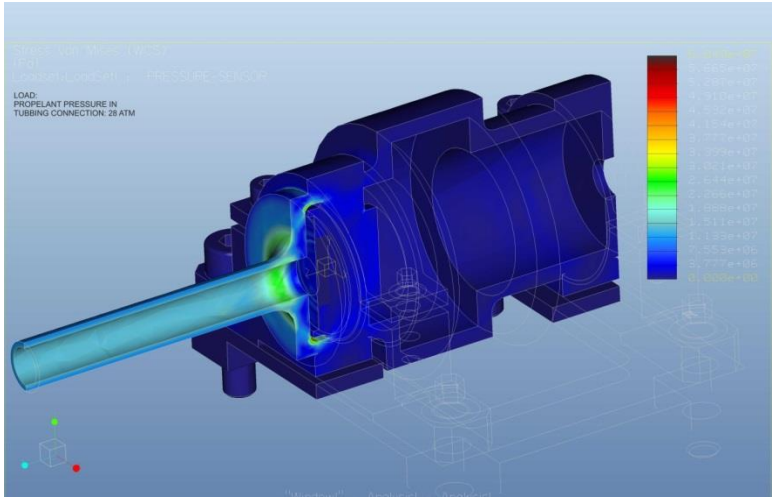
- Mass: 0.25Kg

- Envelope size : 88 (X) x 55(Y) x 36.25(Z) mm

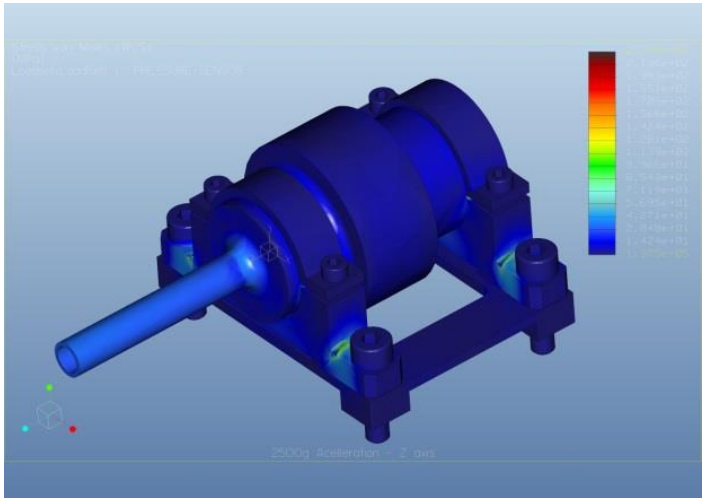


Pressure Transducer

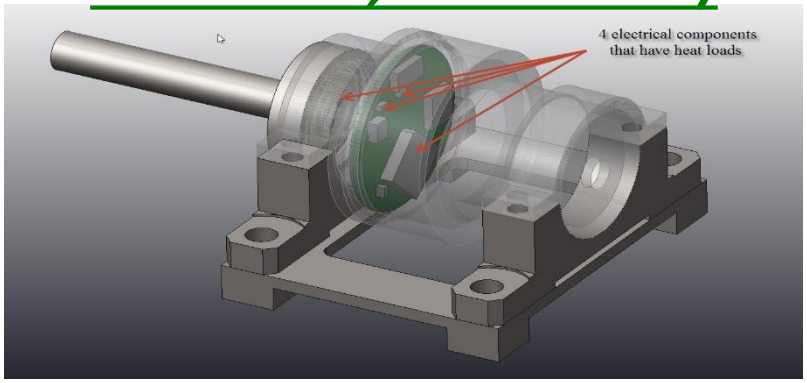
Stress Analysis(Pressure)



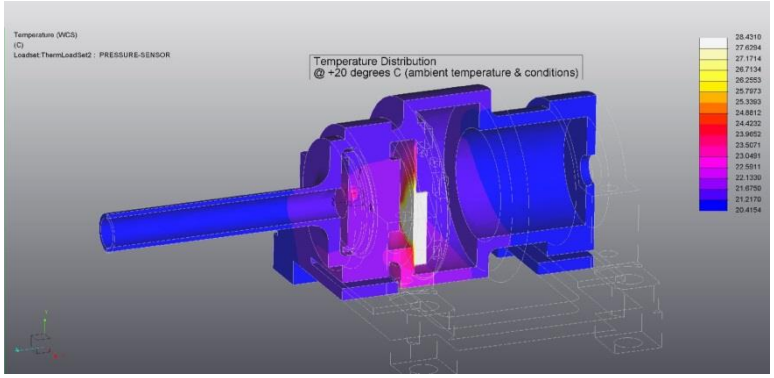
Stress Analysis(Acceleration)



Thermal Analysis (Boundary Conditions, Heat Loads)



Thermal Analysis



Status-Conclusions

- ***PDR & MPCB*** were successfully implemented
- ***CDR*** is planned for Q4 2014

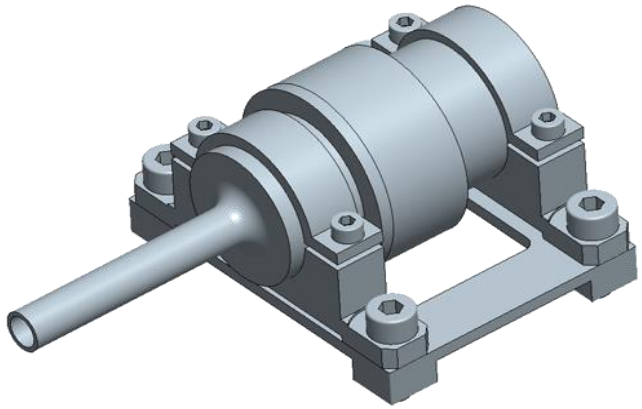
- Early prototypes of MEMS pressure sensors were fabricated based on ESS's fabrication process and proved their functionality

- Test structures of CMOS signal conditioning electronics were fabricated on XFAB XH018 process

- Early prototypes of pressure components (LP & HP) out of Titanium will be fabricated and demonstrated by CDR

- Upon successful CDR, all components will be fabricated to integrate them in the all Titanium Pressure Transducer and proceed until Qualification

Thank you!



Contact Person : ***Emmanuel Zervakis***
General Director
tel: +30 216 2000 500
e-mail: zervakis@esenssys.com

MNT Round Table
10-13 June 2014