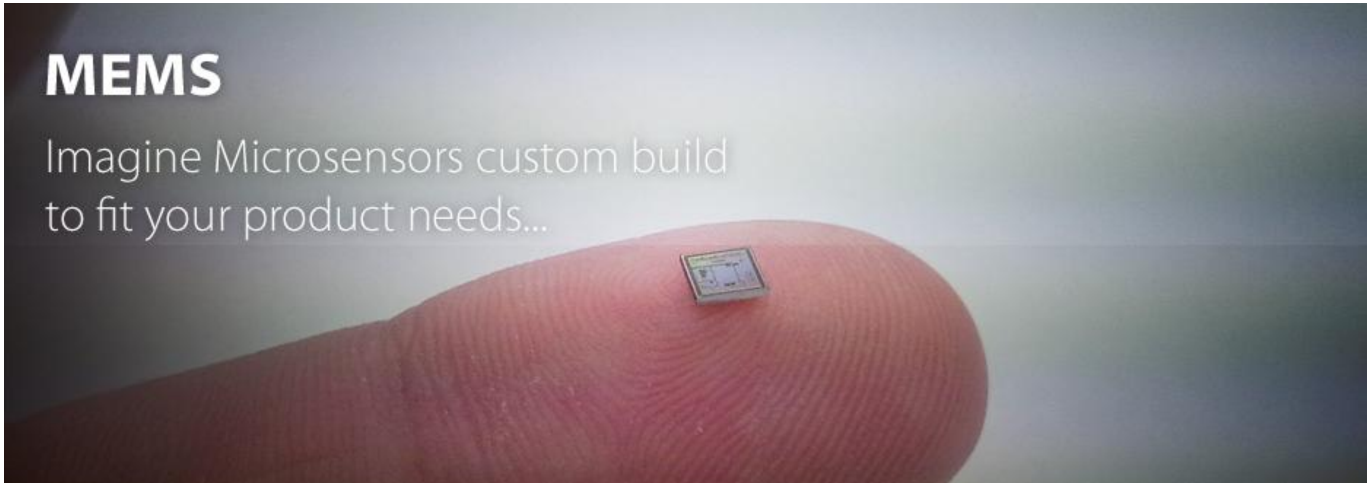


Feasibility Study of a MEMS SOI Capacitive Accelerometer

A. Petropoulos, G. Fikos, R. Triantafyllopoulou, G. Glykiotis,
G. Metaxas, V. Grammatikakis, E. Zervakis

ESTEC, 17 October 2012

www.theon.com

Layout

1. Introduction
    - *About Theon S.A.*
    - *Theon – ESA Background*
2. Existing MEMS capacitive accelerometer
    - *MEMS transducer*
    - *ASIC*
    - *Performance*
3. Accelerometer Redirection activity
    - *MEMS transducer redesign*
    - *ASIC upgrading*
    - *Sensor packaging*
    - *Results*

4. Summary & Roadmap

THEON MEMS activities & products

- **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

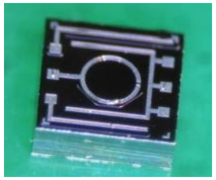
MEMS Fusion Bonding for Capacitive Pressure Sensors (THEON)

MEMS Surface Micromachining for Capacitive Inertial Sensors

MEMS Bulk Micromachining for Resistive Flow Sensors

0.18um Mixed-Signal CMOS

MEMS

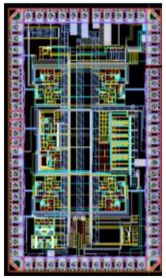


Capacitive Pressure Sensor

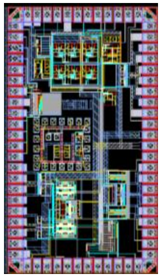
Capacitive Accelerometer

Flow

ASIC



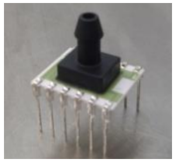
Capacitive Interface



Resistive Interface

Products

Pressure Sensor



Accelerometer

Mass Flow Sensor

THEON – ESA History

1. "Feasibility Study for MEMS-SOI Capacitive Accelerometer" (Sep 2007 - Nov 2008)

- Evaluation /selection of the fabrication technologies for the transducer/ASIC
- Identification / evaluation of the various accelerometer architectures and design topologies
- Selected MEMS/CMOS technologies can serve space applications (based on 5 case studies as provided by ESA)
- Identification of ASTRIUM ST as an end user and Launcher as the target application

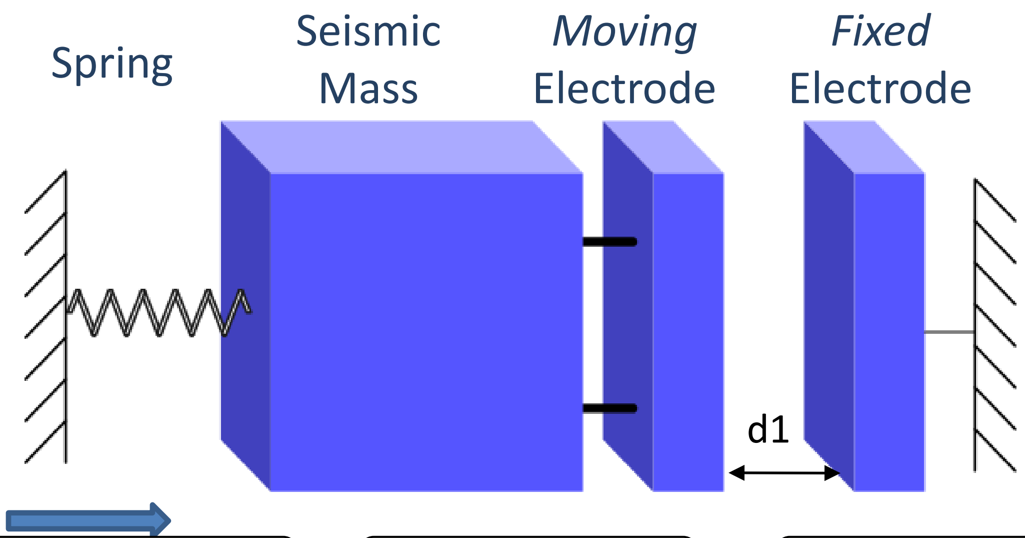
2. A. "Flight Demonstrator for a MEMS Accelerometer for Launchers" (Sep 2009 - PDR on Dec 2010)

- Design and fabrication of MEMS transducer
- Design and fabrication of CMOS signal conditioning electronics
- The activity successfully reached PDR, when it became evident that there was insufficient market and the activity was redirected

B. "Accelerometer Re-direction study"

- Extraction of detailed specifications from ESA requirements
- High performance 1-axis accelerometer component
- Re–design of the MEMS transducer based on the already selected technology
- Re-design of the CMOS signal conditioning electronics on the already selected technology
- New packaging design

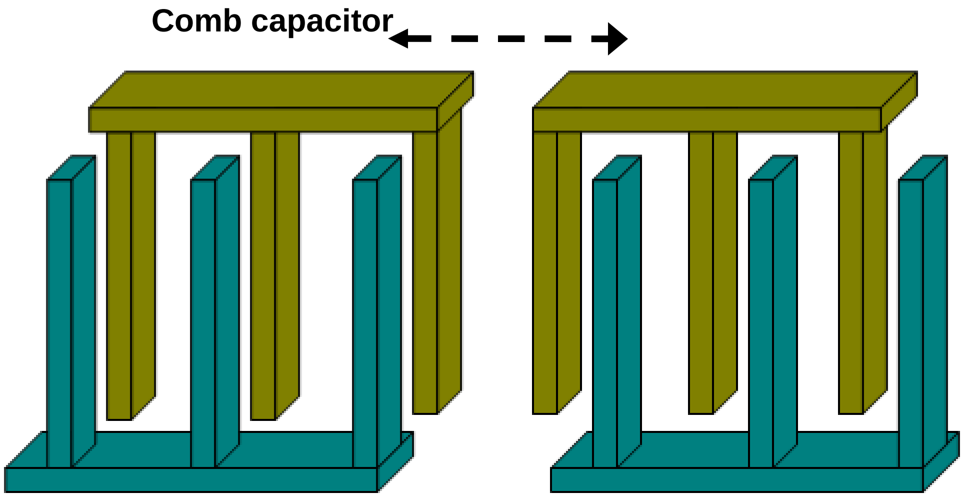
Acceleration Measurement – Capacitive principle



Acceleration → Displacement → Capacitance change

☐ Capacitance Formula

$$C = \frac{\varepsilon A}{d}$$



☐ Capacitor structure:

- Double capacitor structure provides more ***linear*** response
- Comb drive structure increases measured capacitance

Fabrication Technology

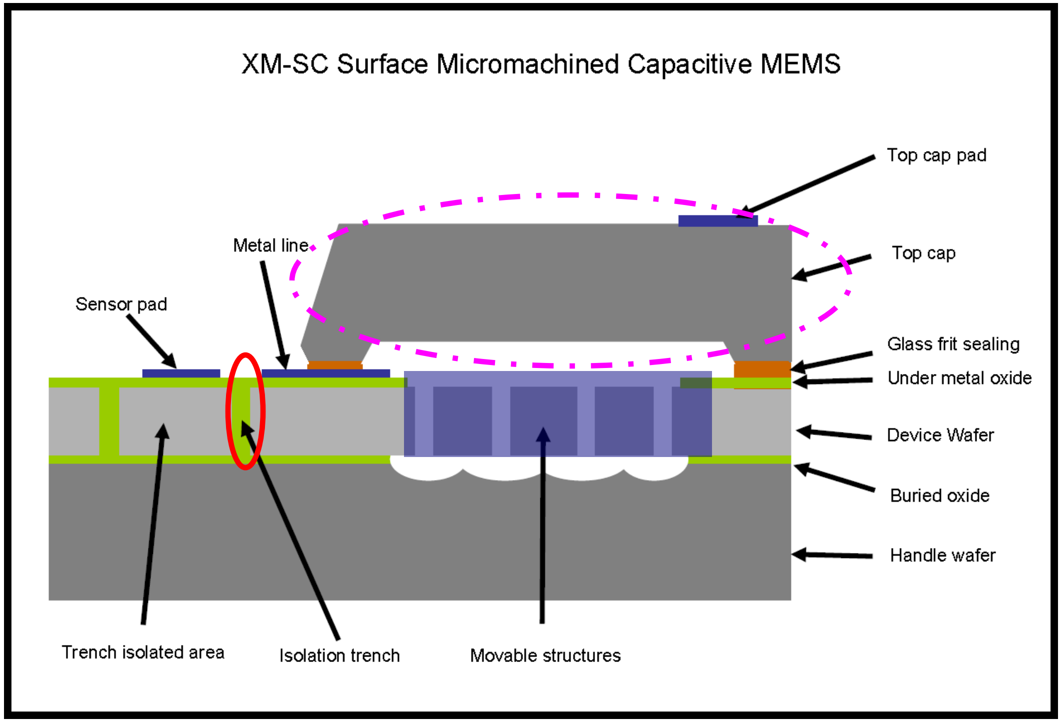
MEMS Fabrication Technology:

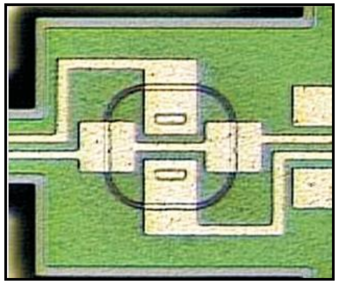
- Surface Micromachining of SOI wafers

<u>SOI wafers Technology</u>

Perforation holes needed to ensure final release
Fixed Thickness DL with 2µm minimum feature size

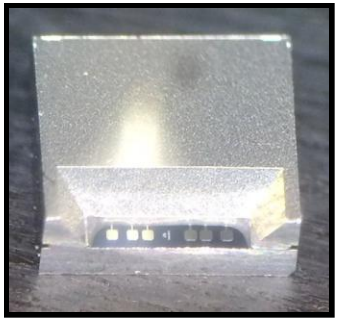
X-Fab's XM-SC Technology for Capacitive MEMS inertial Sensors





<u>Isolation trenches:</u>

Isolate electrically parts of the accelerometer and guarantee the wafer level encapsulation



<u>Wafer Level Encapsulation:</u>

Built in pressure: 0.1Bar or 0.4 Bar
Suppression of the thermo-mechanical (Brownian) noise

Redirection activity

Redirection specification set

Goal: *Developement of high performance 1-axis accelerometer*

- Individual elements re-design and simulation (MEMS & ASIC)

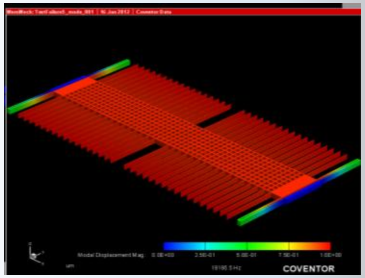
- Simulation of device performance at the system level

- New packaging scheme

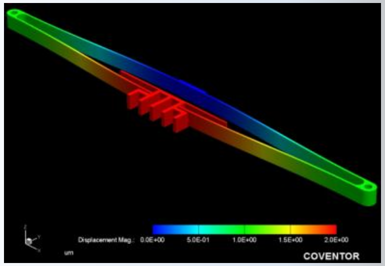
- Certain parameters acquired from measurement of the already fabricated devices

- Two distinct designs for the ±2g (ACC_2g) and the ±20g (ACC_20g) cases

Individual element modeling



- ❑ Resonance Frequency
- ❑ Spring constant definition
- ❑ Damping Factor
- ❑ Finger number and relative positioning

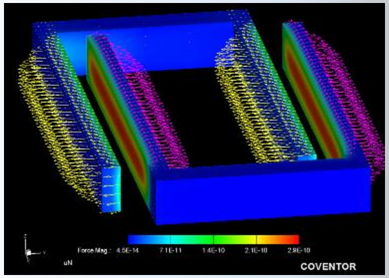


Design optimization

❑Mass

Increased mass size - reduction of electromechanical noise

Altered shape - Increase perimeter / surface ratio



❑ Fingers

Increased number of fingers - increased scale factor

Finger relative positions - maintain high linearity

Force Fingers – perform self test when in orbit

ASIC improvements

C-to-V Converter

Specification	Existing (measured)	Improved (simulated)	Unit
Output Noise (rms BW=1 to 100Hz, **no** chopping)	430	166	μV
Output Noise (rms BW=1 to 100Hz, **with** chopping)	106	42	μV

- **Noise reduction technique for low-frequency noise suppression**
- **Improved low-noise Opamp**
- **Digital balancing for mismatch compensation of input capacitance**
- **Digitally trimmable gain**

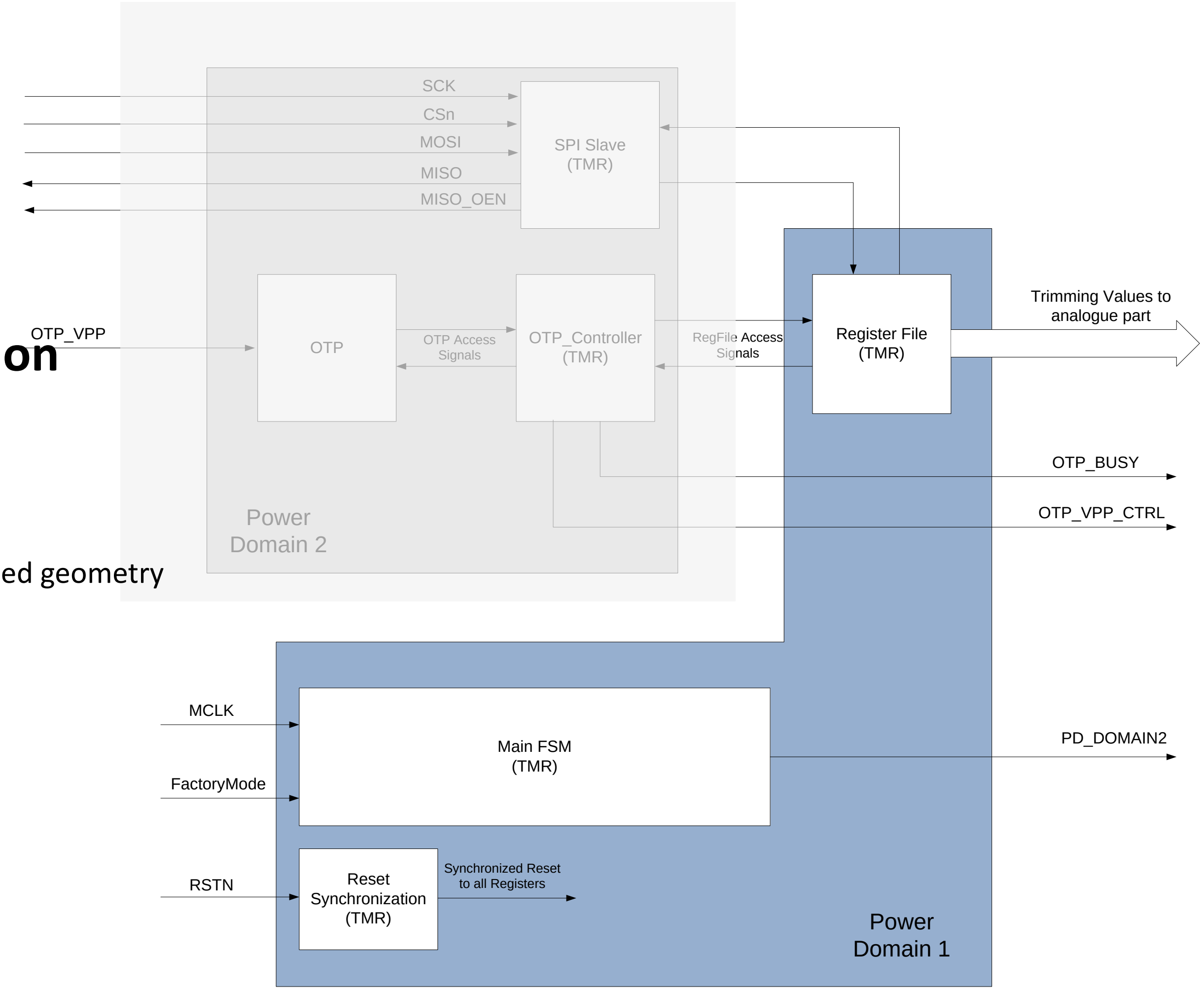
Instrumentation Amplifier

Specification	Existing (measured)	Improved (simulated)	Unit
NL_{MAX}	1.05	0.001	% FSO

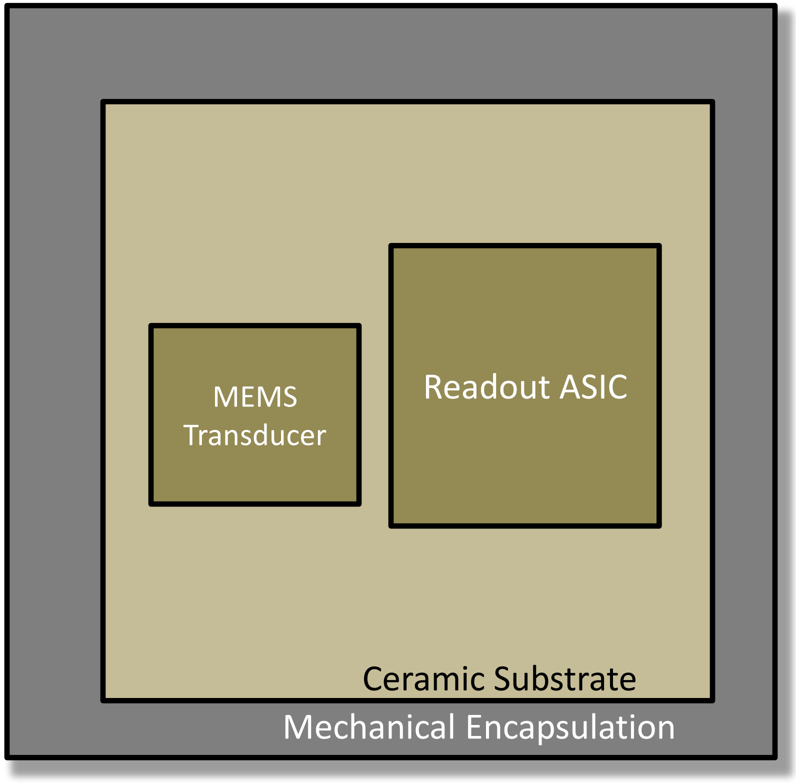
- **Linearity increase**

ASIC's radiation hardening

- **TMR technique**
- **Power Domain Separation**
- **Layout techniques**
  - Implementation of devices in enclosed geometry
  - P+ guard ring around NMOS devices
  - N+ guard ring around PMOS devices



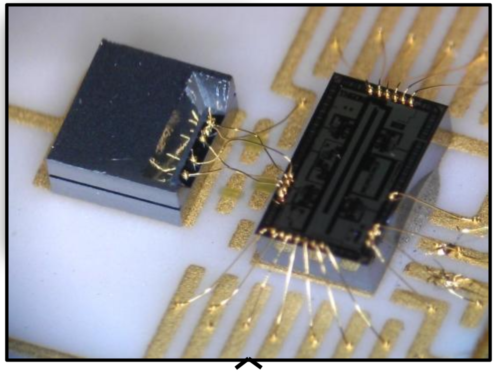
Packaging options

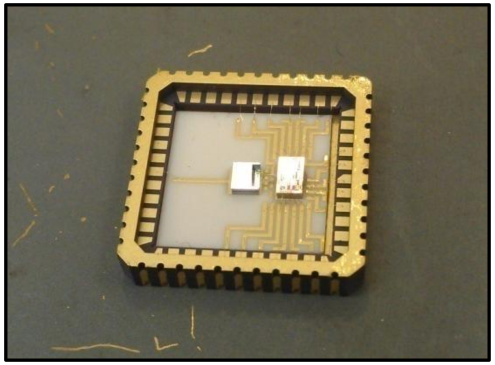

MEMS Transducer

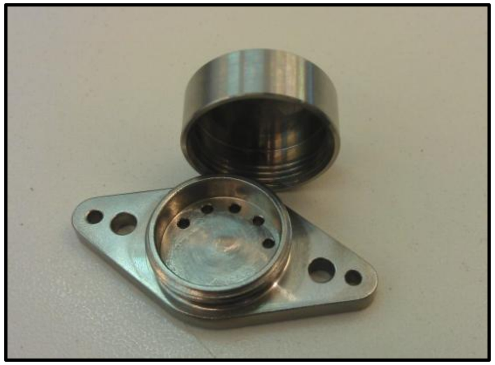
Readout ASIC

Ceramic Substrate

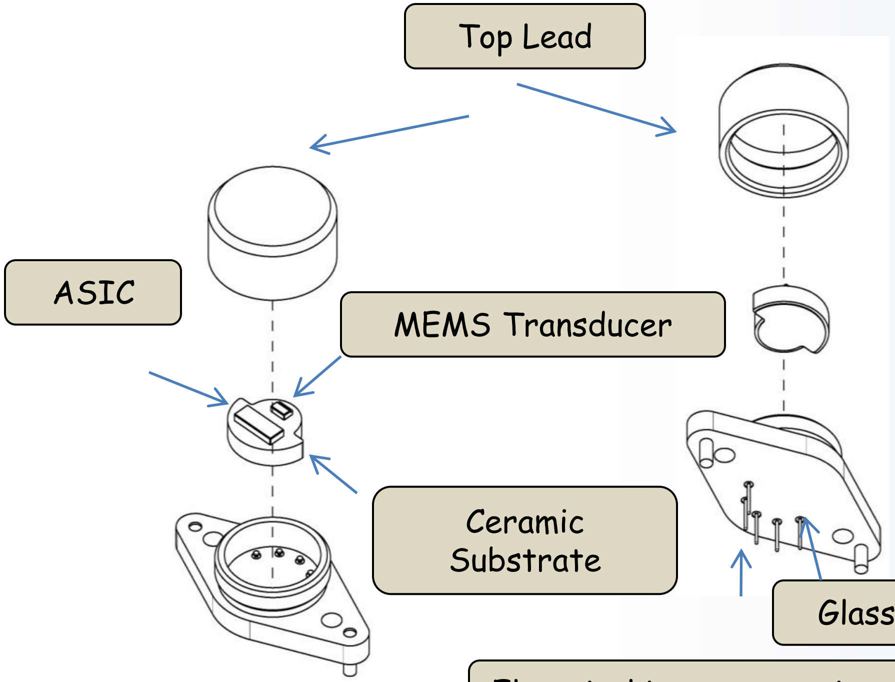
Mechanical Encapsulation




QFP Ceramic packaging


TO Metallic can package

Accelerometer packaging - fabrication



Top Lead

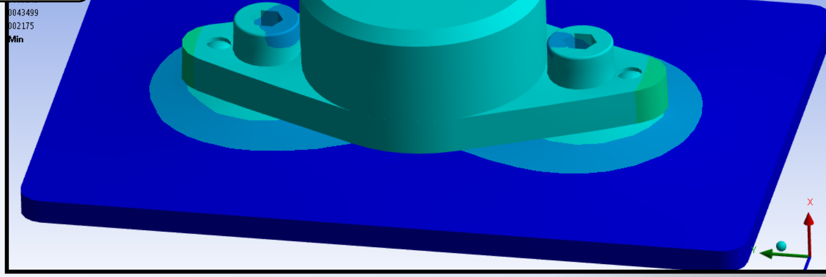
ASIC

MEMS Transducer

Ceramic Substrate

Glass Frit Sealing

Electrical interconnection pins



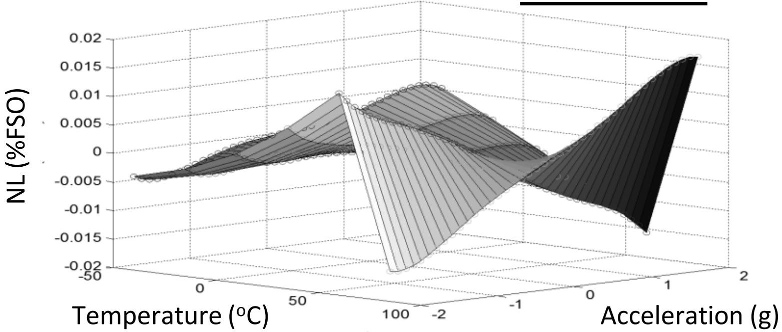
Characteristics

1. Easy to assemble
2. Ruggedized for shock and vibration environments
3. Direct alignment by use of dowel pins
4. Vacuum encapsulation of MEMS and ASIC
5. Small dimensions; further minimization feasible
6. Minimal cost solution for low volume production

Overall System Results

	Parameter	ACC_20g (*simulated*)	ACC_2g (*simulated*)	XLM11 (*measured*)	Units
MEMS	**Sense Capacitance at Rest**	650	770	200	fF
	Capacitance Change	120	90	30	fF
	MEMS NL	±0.4	± 0.4	± 0.4	% FS
	Scale Factor	6.1	46.5	3	fF/g
	Resonance	4.1	2.5	3.5	kHz
	Brownian Noise	12.5	15.5	32.1	µg/√Hz
System	**System Resolution**	16	14.2	12.1	bits
	System NL (Raw)	0.5	0.5	0.4	% FS
	System NL (Compensated)	0.019	0.016	-	% FS
	Zero-g Temperature stability	-	-	250	ppm/^{o}C
	Scale Factor Temperature Stability	-	-	182	ppm/^{o}C

System level linearization



$$a_{in,calc} = \sum_{i=0}^{3} p_i(T) V_{out}^{i}$$

System Resolution:

Limited by ASIC noise (electronics noise an order larger than Brownian noise)

Summary - Roadmap

- Based on previous experience, a redesign of existing devices in order to meet demanding requirements was conducted.

- The simulation results revealed that the majority of the requirements were fullfilled.

- Continue the evaluation of the fabricated MEMS transducers, CMOS ASIC’s and packaged components

- Fabrication of ACC_2g & ACC_20g transducers on Q1 2013

- Development of a radiation hardened CMOS ASIC for signal conditioning of capacitive sensors based on 0.18um XFAB

G. Fikos
R. Triantafyllopoulou
G. Glykiotis
G. Metaxas
V. Grammatikakis
E. Zervakis

S. Airey

Thank you!

Tasos Petropoulos
email: petropoulos@theon.com