MEMS INDUSTRY GROUP™

MEMS Industry Group Presents

Concurrent Design to Achieve High Performance and Low Cost: Case Study of a MEMS Automotive Pressure Sensor Design

Presented by David DiPaola, Managing Director, DiPaola Consulting

Moderated by Rob O'Reilly, Senior Member Technical Staff, Analog Devices

December 13, 2011

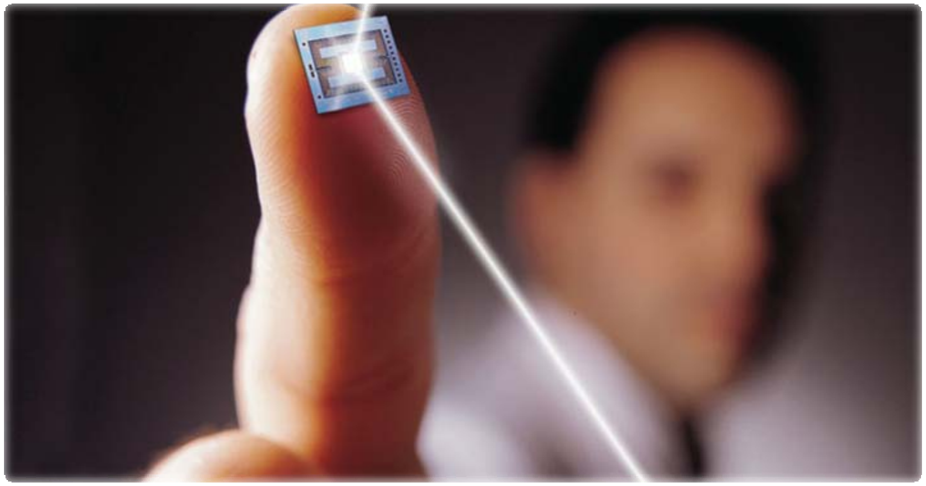
Hosted by Karen Lightman, Managing Director, MEMS Industry Group

www.memsindustrygroup.org

MEMS Industry Group (MIG)
Introduction

Over **130 members and partners** – from start-ups to Fortune 500 companies

MIG members ARE the MEMS supply chain.



MIG Mission

MEMS INDUSTRY GROUP™

MEMS Industry Group is the trade association advancing MEMS across global markets

What We Do

Educate the Marketplace

- Explain why MEMS is important and how it's being used
- MEMS in the Machine

Encourage Information-sharing

- Steering Committees, Industry News, PR Opportunities, MEMSblog, Twitter, LinkedIn, YouTube and newsletter
- MEMS Marketplace, one-stop matchmaking portal for MEMS supply chain and their customers
- Collaborative Projects – MEMS Foundry Engagement Guide

Share Resources

- White Papers, Industry Data, Presentations
- Membership Directory
- Introductions
- Webinars, workshops and networking

AKUSTICA Bosch Group
ANALOG DEVICES
MEMS and NanoTechnology Exchange
ClassOne EQUIPMENT
AMERIMADE Technology Inc.
DRAPER LABORATORY
VTI TECHNOLOGIES
ABIresearch technology market intelligence
AVAGO TECHNOLOGIES
BOSCH Invented for life
BULLEN ULTRASONICS, INC.
siconnex customized solutions
OXFORD INSTRUMENTS
RITE TRACK
movea
Expertech
baolab MICROSYSTEMS
MERIT SENSOR Performance Under Pressure
apm Asia Pacific Microsystems, Inc.
iNEMI
EPSON EXCEED YOUR VISION
Plasma-Therm
MEPTEC
XACTIX
ACUTRONIC
Fraunhofer ISIT
SSSco
IQE
Honeywell
Commercial Micro Manufacturing Magazine
PLURES TECHNOLOGIES, INC.
RADANT MEMS
APPLIED MATERIALS
chipworks inside technology
Semefab
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imt
memsstar
APPLIED MST
探微科技 Touch Micro-System Tech.
EPCOS
MEI
AKrion systems
COVENTOR
freescale
OMRON
Polytec
SolidState TECHNOLOGY
AMFITZGERALD
Acuity
MEMSTAFF
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Qualtré
Icemos Technology
micronit MICROFLUIDICS
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SVTC
MEMSCAP The Power of a Small World
Agency for Science, Technology and Research SINGAPORE
csr
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SmallTech Consulting
Kilbrydon
OEM GROUP
SUSS MicroTec
TELEDYNE DALSA A Teledyne Technologies Company
Nanoshift
ST
STC
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MEMS VISION
NSTI Nano Science and Technology Institute
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OKMETIC
SoftMEMS Bringing MEMS to the Mainstream
Centipede Systems
NOKIA Connecting People
MEMS Park Consortium
IHS has acquired iSuppli
NIST
micralyne
OAI
MEMS INVESTOR JOURNAL
YOLE DÉVELOPPEMENT
Eric Levy-Myers

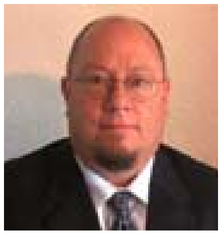
Upcoming MIG Events

MEMS INDUSTRY GROUP™

- **MEMS Education Series – Webinars**
  - January 17 – Improving Performance of New MEMS Designs: An Insider's Look at imec's SiGe above-IC MEMS Technology Platform
  - February 16 – MEMS Reliability Case Study
  - February 23 – MEMS Product Life Cycle
- **MEMS TechZone & Conference Session at CES 2012**
  - January 10-13, 2012 – Las Vegas
- **MEMS Executive Congress – Europe and US**
  - March 20, 2012 – Zurich, Switzerland
    November 7-8, 2012 – Scottsdale, AZ
- **Sensors in Design – ESC Silicon Valley**
  - March 28-29, 2012 – San Jose, CA
- **M2M Forum – MEMS New Product Development**
  - May 8-9, 2012 – Pittsburgh, PA
- **Sensors Expo Chicago**
  - June 4-6, 2012 – Rosemont Convention Center

Today's Speakers

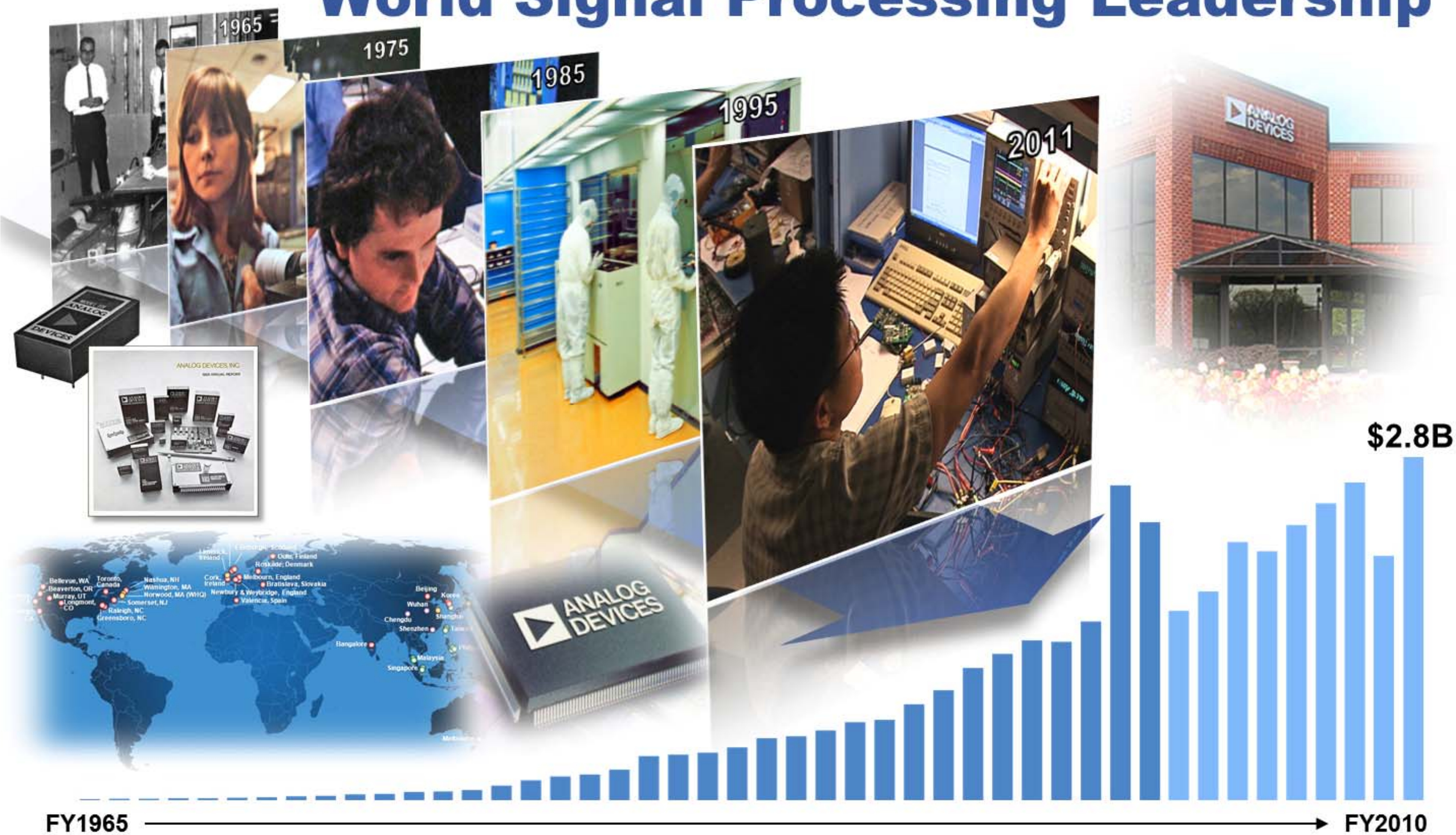
MEMS INDUSTRY GROUP™



- Moderator
  - Rob O'Reilly, Senior Member Technical Staff, Analog Devices

- Presenter
  - David DiPaola, Managing Director, DiPaola Consulting

Innovation Has Driven 45+ Years of Real-World Signal Processing Leadership



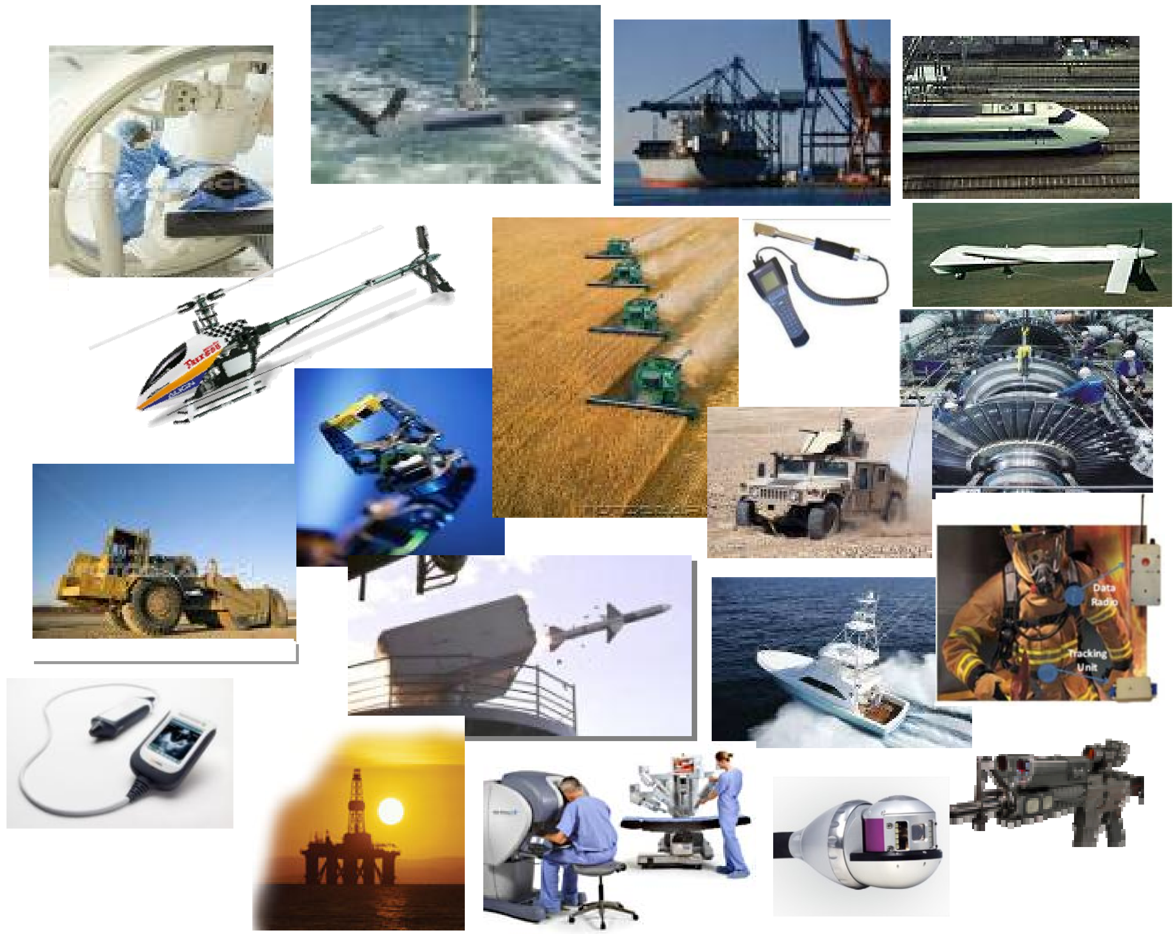
Source: *ADI revenue history from ADI financial data. Years FY2002-FY2010 represent continuing operations.*

ANALOG DEVICES

ADI Inertial Technology +
ADI Signal Processing Strength =
Optimal Solutions to High performance Applications

THEN

NOW



Concurrent Design to Achieve High Performance and Low Cost: Case Study of a MEMS Automotive Pressure Sensor Design

David DiPaola, Managing Director
www.dceams.com

Who is DiPaola Consulting?

- A company located in in Gaithersburg, MD specializing in electromechanical design and process development
  - Extensive experience in MEMS sensors
  - 3D parametric modeling, multiphysics FEA, electrical simulation, ion implantation, silicon etch, tolerance stack, design of experiments, Matlab
  - Automotive, biomedical, consumer, military and industrial applications
- Expert problem solvers with a proven history of developing and launching new products with next to zero failures
- Product technology and material selections
- Excellent relationship with prototype and production pure play foundries
  - MEMS prototype, foundry selection, production part approval process
- Measurement system analysis, metrology, full product validation capabilities

Agenda

- Problem Statement
- Sensor Specifications
- Sensor and MEMS Sense Element Designs
- Influence of Concurrent Design in Achieving Lowest Cost
- Finite Element Analysis of Design to Predict Sensor Performance
- Summary of Analysis
- Conclusions

Sensor Problem Statement

- Develop an array of pressure sensors with limited height to measure input from multiple sources in an harsh automotive environment
- Maintain high accuracy during extreme temperatures, temperature transient events and nonplanar boundary conditions Topic for this discussion
- Meet stringent drift requirements throughout life when exposed to vibration, thermal cycle / shock, high / cold temperature endurance, operating and proof pressure cycling
- Prevent sensor mechanical failure during burst pressure loading
- Prevent environmental ingress into the sensor package
- Support compression stack load of other system components
- Achieve low cost for high volume proliferation

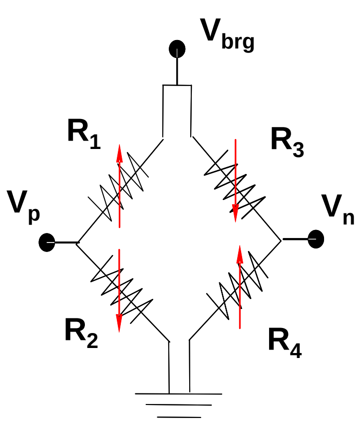
MEMS Pressure Sensor Specifications

- Operating Pressure Range: 100 – 1500 KPa (220 PSI)
- Sensor Output: 0 – 5 VDC or digital interface (CAN or SPI typical)
- Operating Temperature Range: -40 to 140°C (short excursions higher)
- Proof and Burst Pressure: 2X and 3X operating respectively
- Full Scale Pressure Cycles: 10 Million
- High Temperature Endurance: 500 hrs at 140°C
- Vibration: 4g RMS for > 250 hrs
- Initial Accuracy (Total Error Band): ≤ 2% Supply Voltage
- Drift Over Life: ≤ 2% Supply Voltage
- Response Time: 1 msec

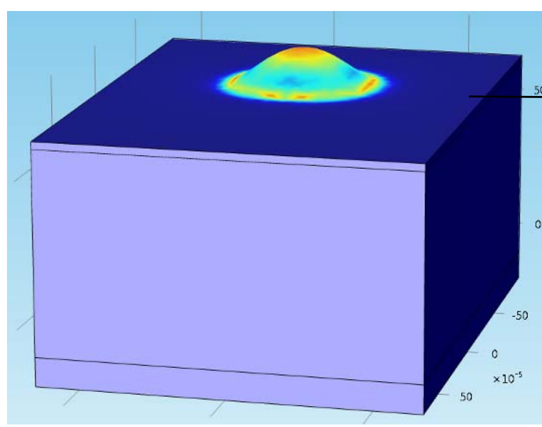
MEMS Sense Element Design

- Piezoresistive MEMS technology selected for sense element
  - Limited height when integrated into sensor package
  - Easier to thermally isolate from package to achieve excellent temperature transient performance
  - Low cost for multiple pressure inputs
  - Piezoresistor full Wheatstone bridge and central signal conditioning ASIC for all sense elements

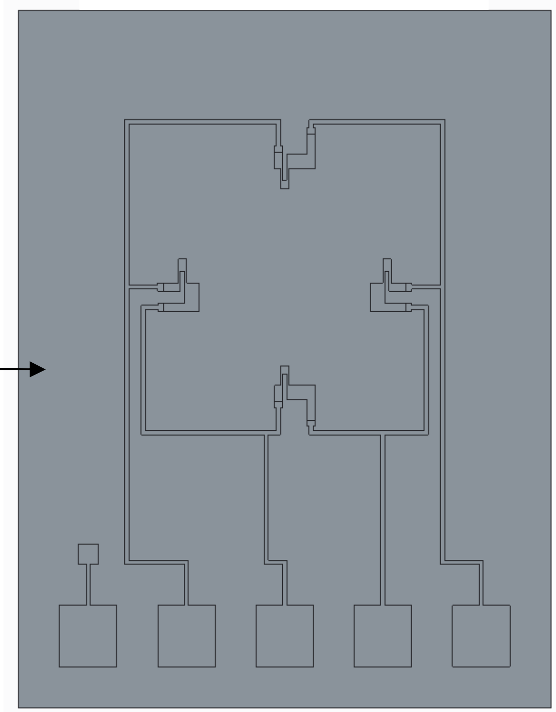
Full Bridge



SOI Sense Element

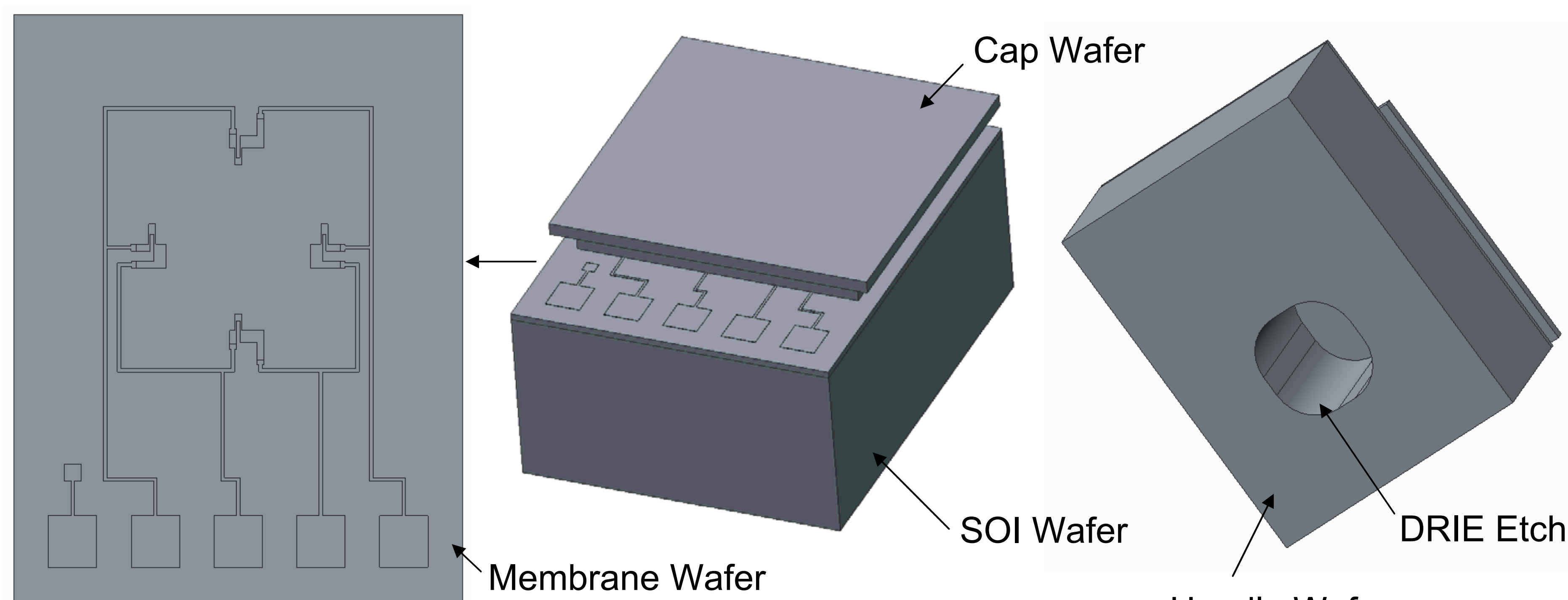


Membrane Wafer



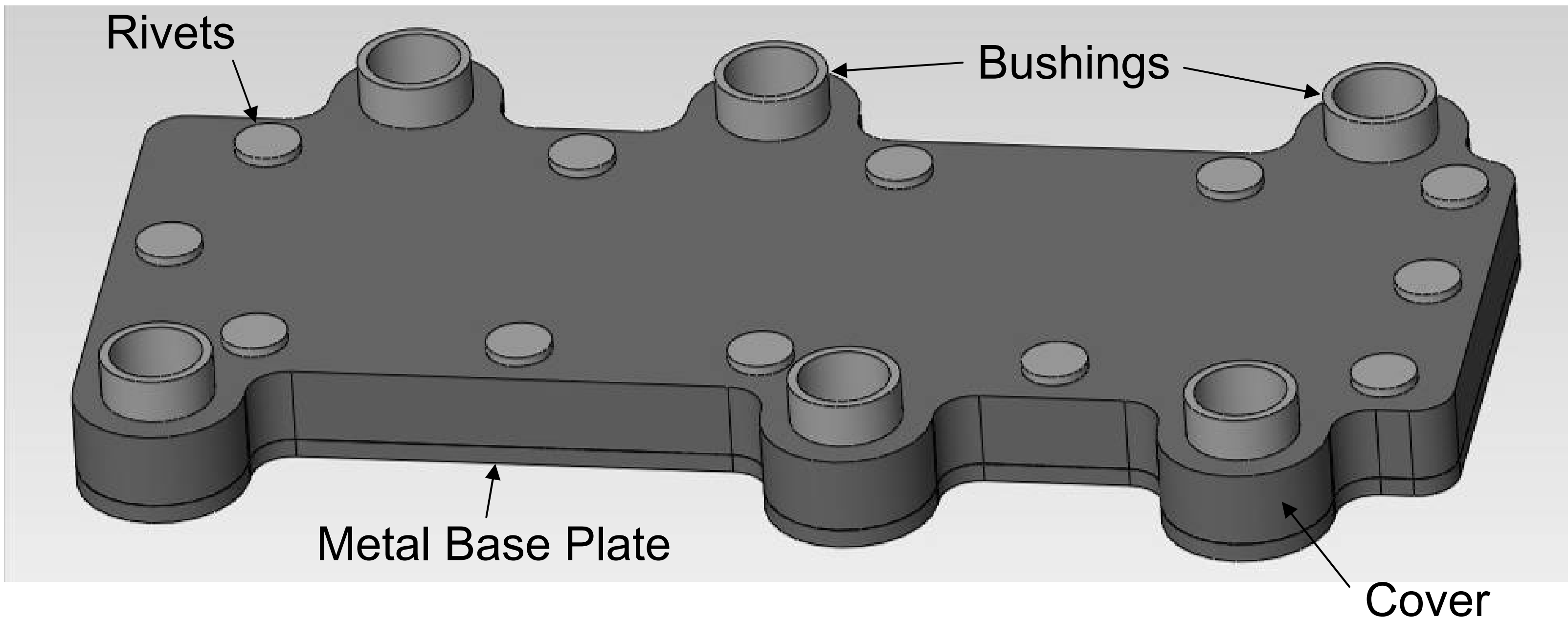
MEMS Sense Element Design

- SOI wafer approach with reference cap (silicon or glass)
- Scalable to 7000 KPa or 1000 PSI
- Designed concurrently with packaging and foundry manufacturing process
- 3X cost saving from foundry over full service supplier (in high volume)



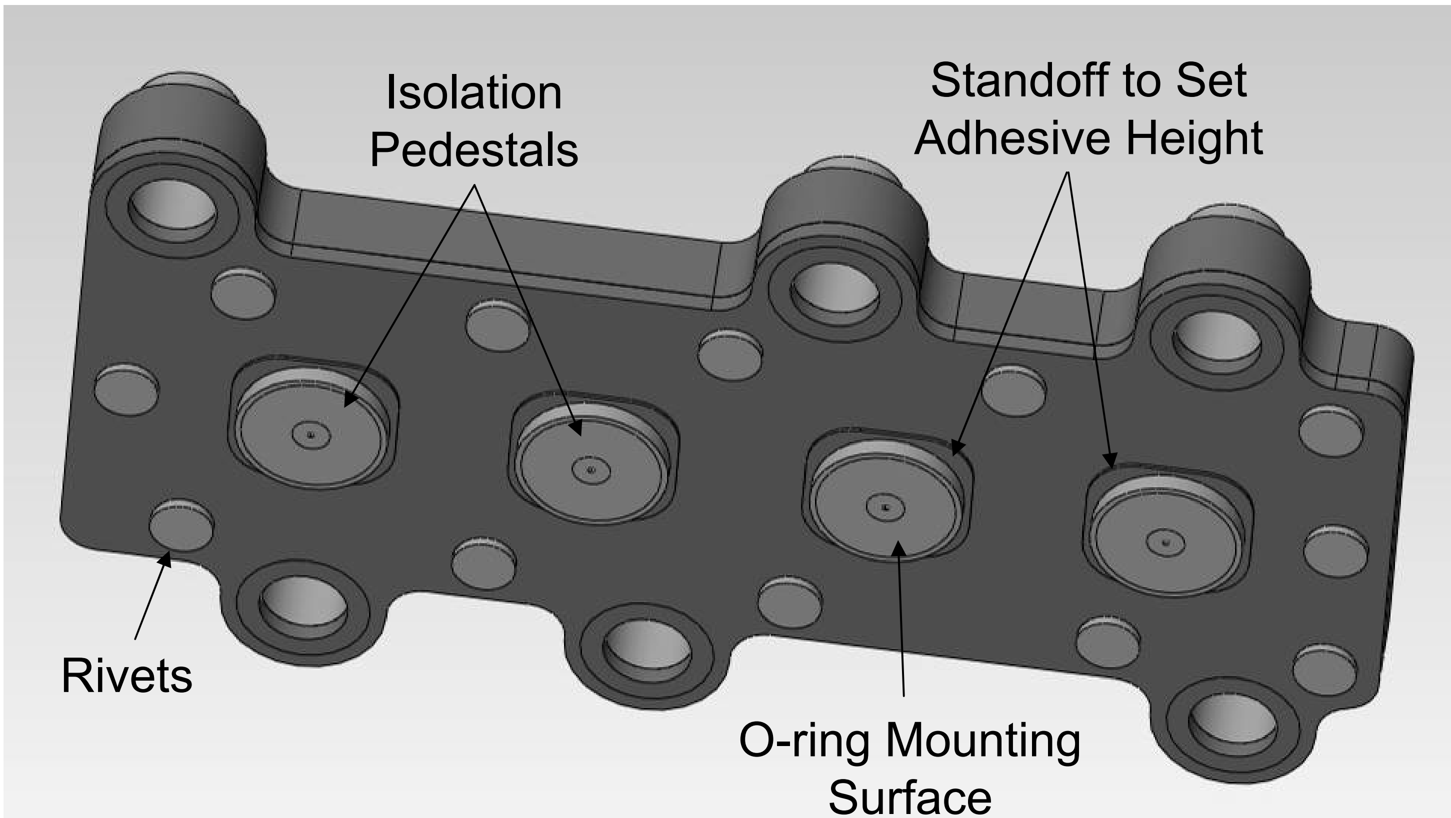
Pressure Sensor Design

- Isometric View of Sensor



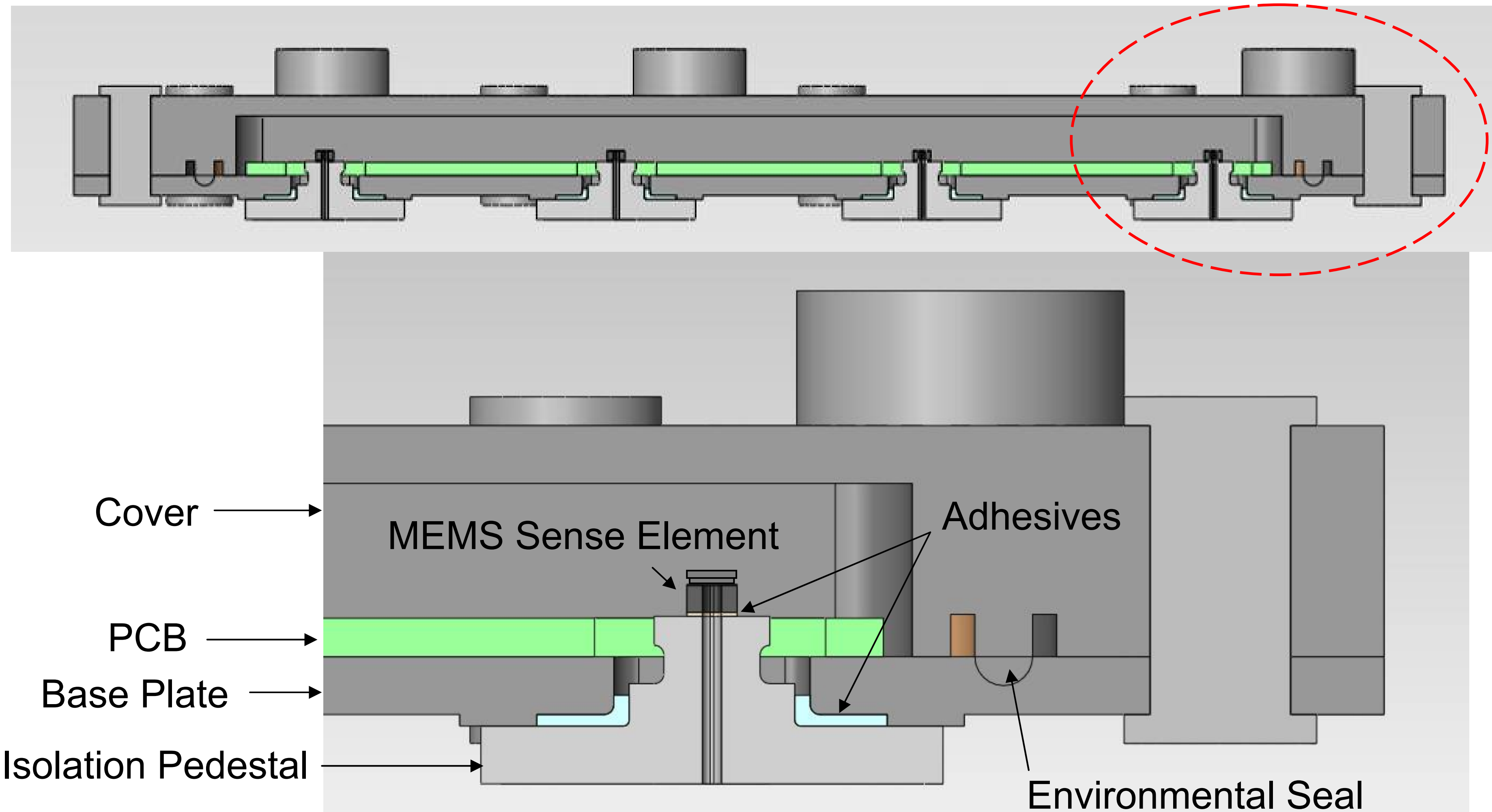
Pressure Sensor Design

- Bottom Side



Note: O-ring gland located in customer manifold

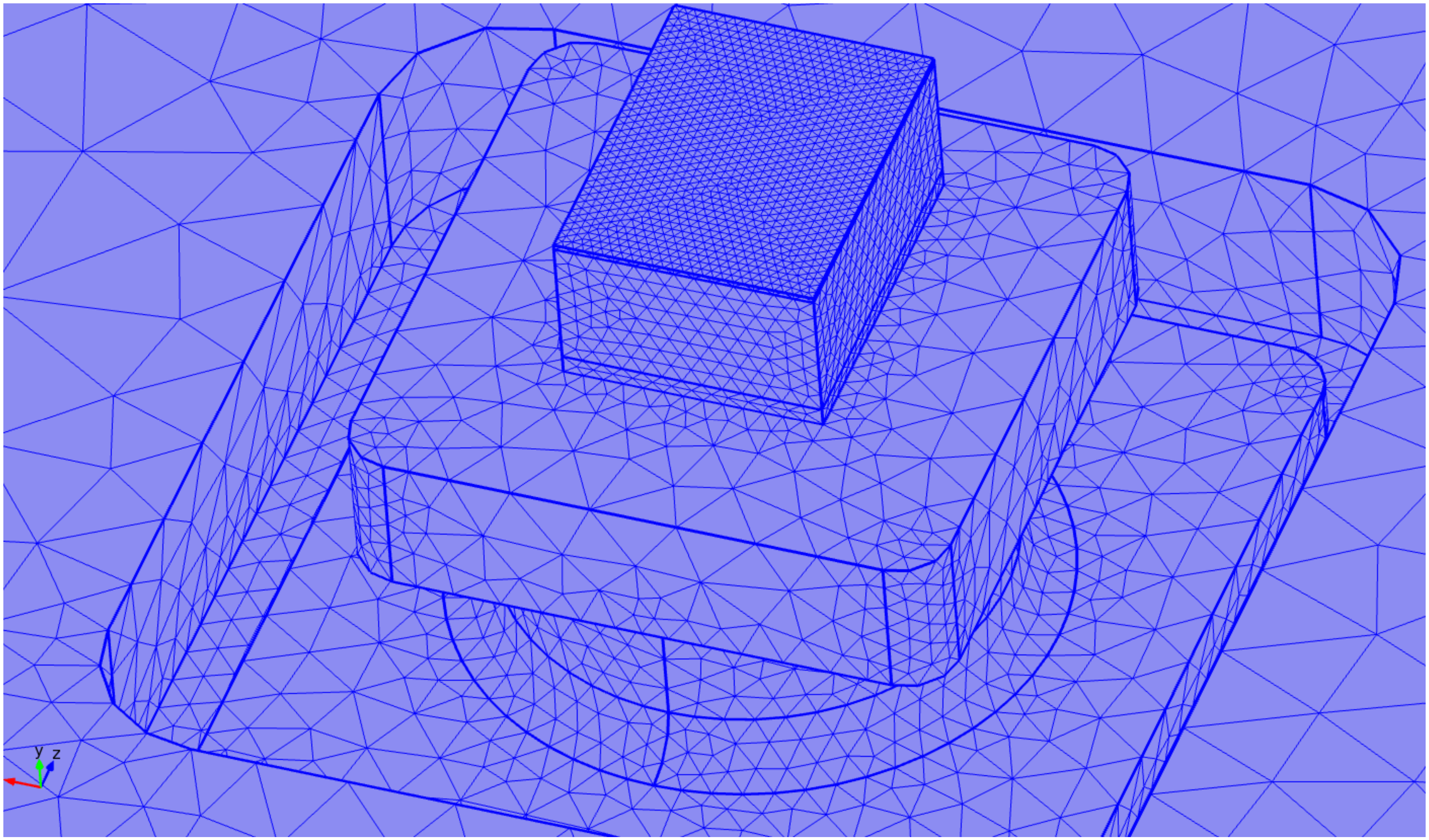
Cross-section Views of Sensor Design



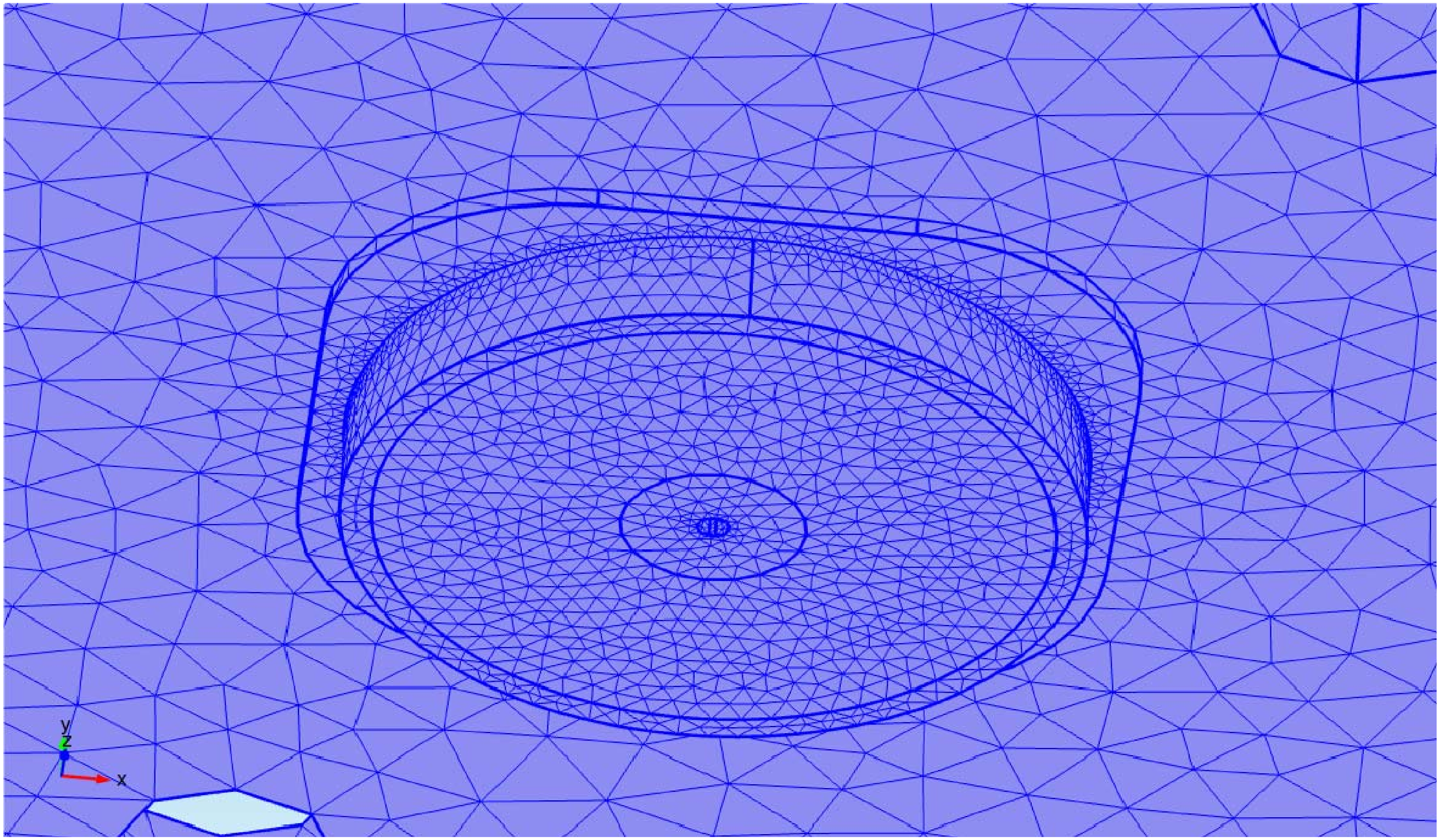
Design Approach Guided by Finite Element Analysis

- Sensor output sensitivity to mounting boundary conditions was the largest challenge in the design phase
- Boundary conditions are not ground flat to significantly reduce cost of system
- Finite element analysis used to validate design approach prior to prototype
  - COMSOL Multiphysics 4.2 was used for the finite element analysis
  - SolidWorks was used for 3D modeling
  - Sense element cap and sensor cover not included in analysis
- Two approaches considered for mounting MEMS sense element:
  - Directly on metal base plate
  - On isolation pedestal bonded to metal support plate

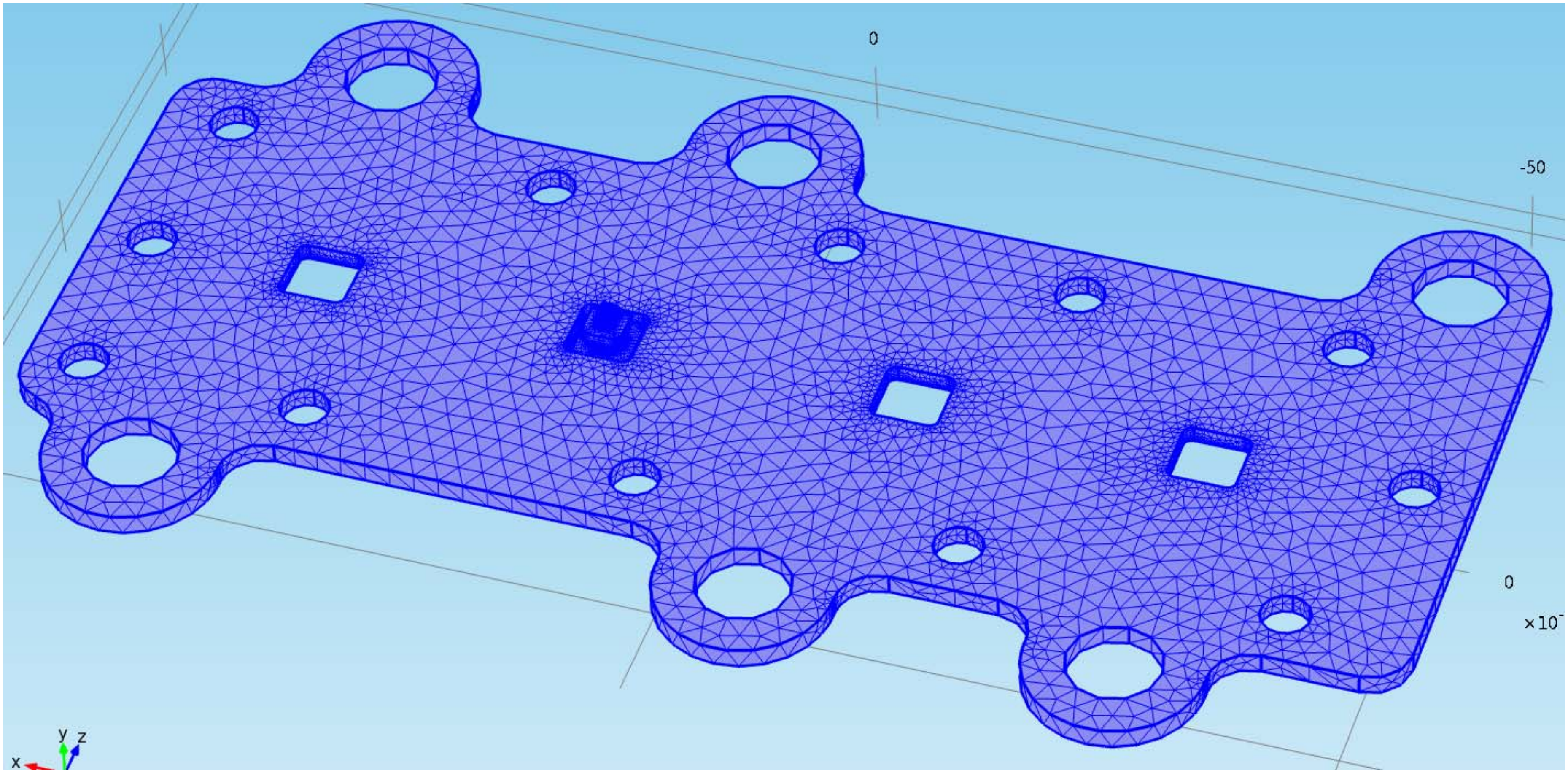
FEA Mesh



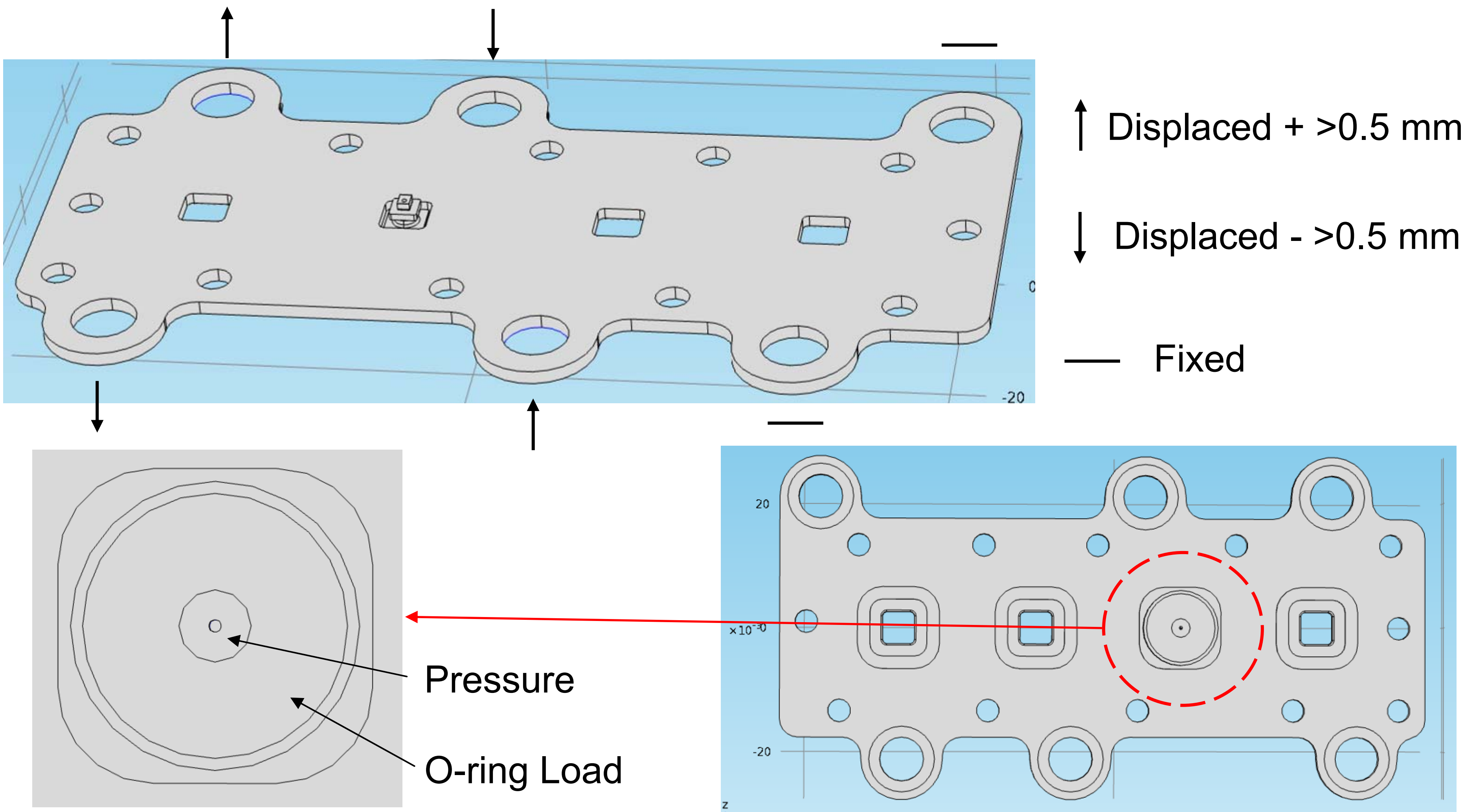
FEA Mesh



FEA Mesh

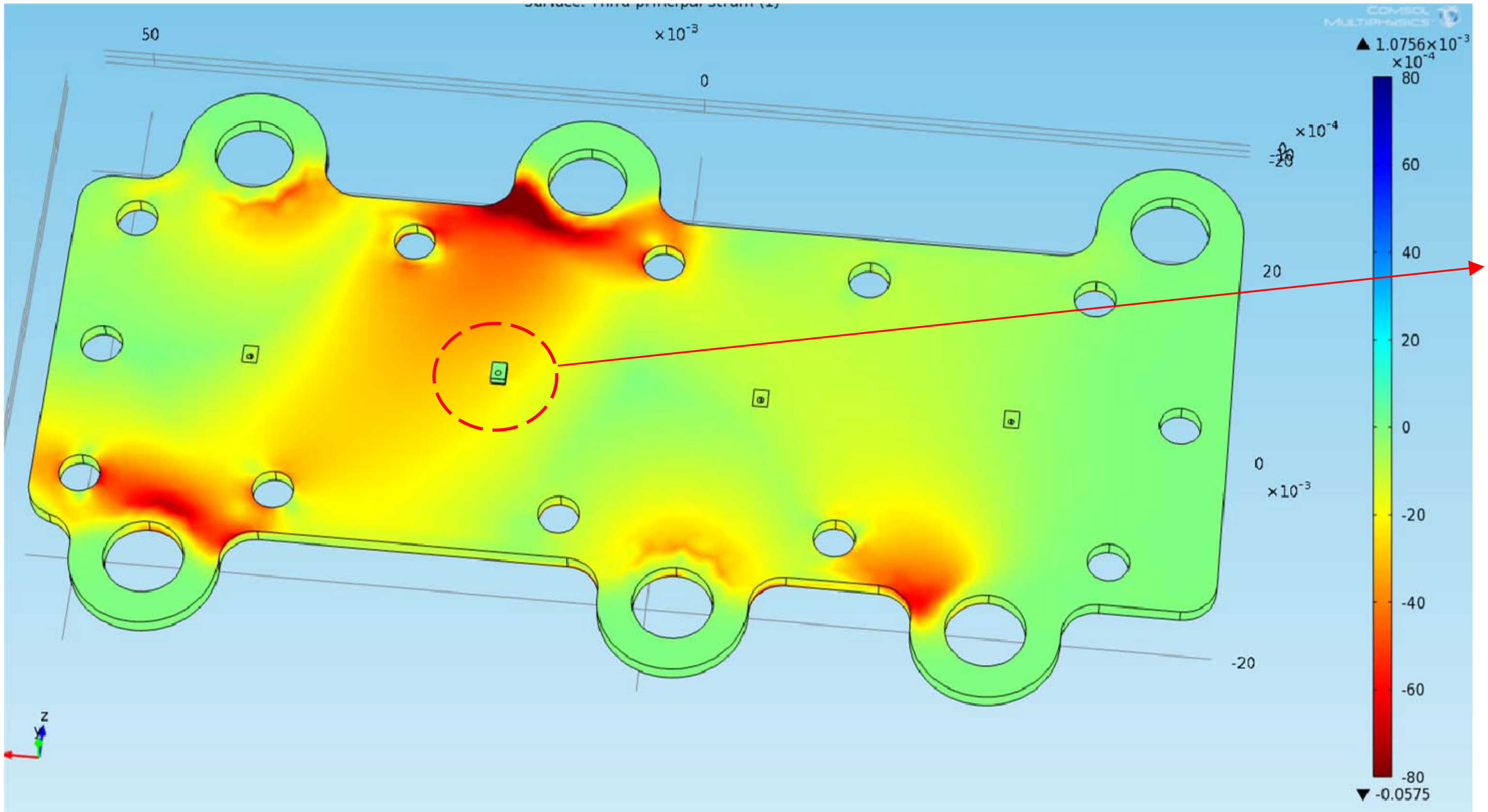


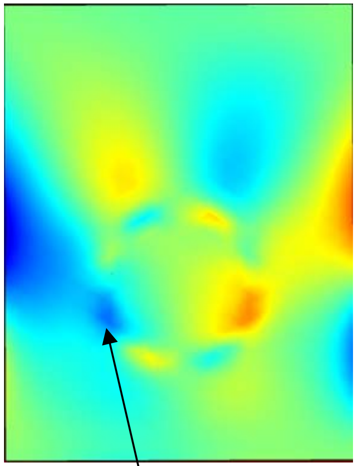
FEA Boundary Conditions



FEA Results of MEMS Mounted on Metal Base Plate

- Predicted sensor error due to mounting: 1.8% of Sensor Span
- Correlation between theoretical and actual sensor error > 90%



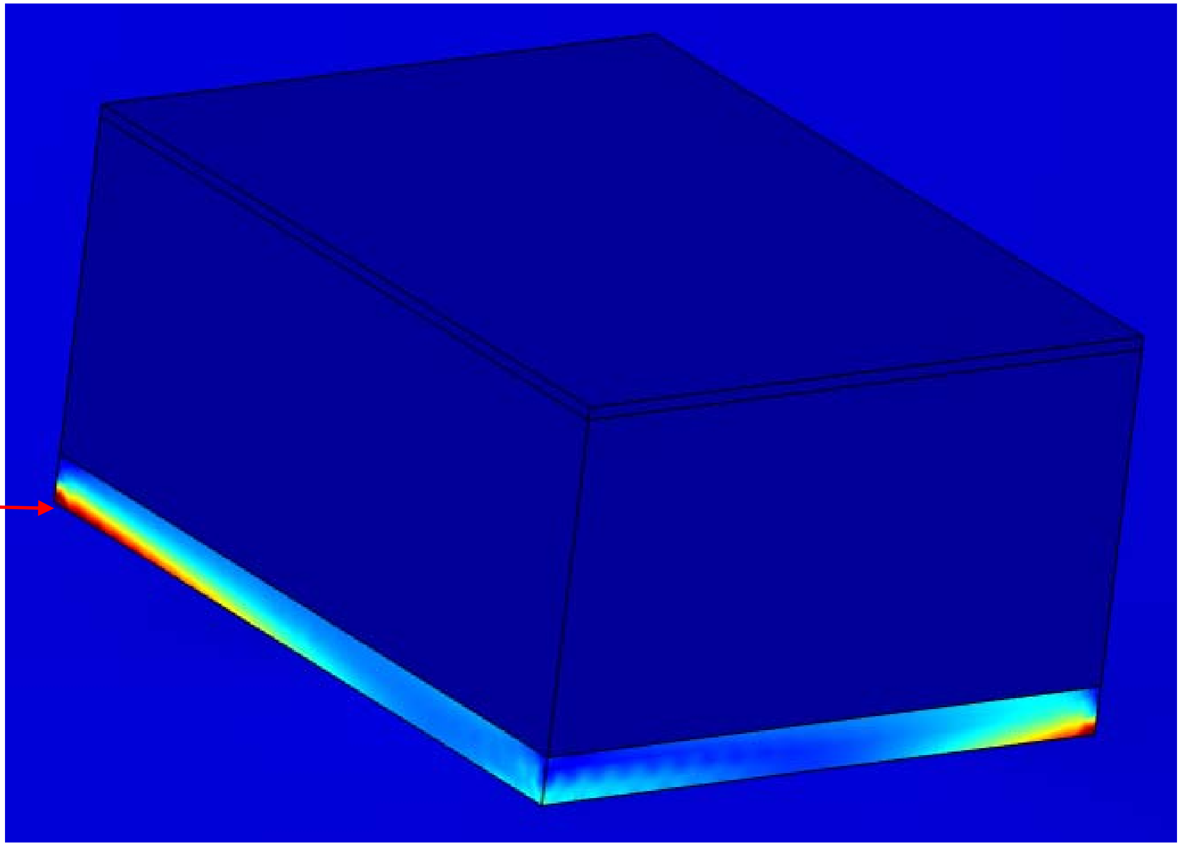


Max
15 µstrain
on MEMS
Die Surface

FEA Results of MEMS Mounted on Flat Plate

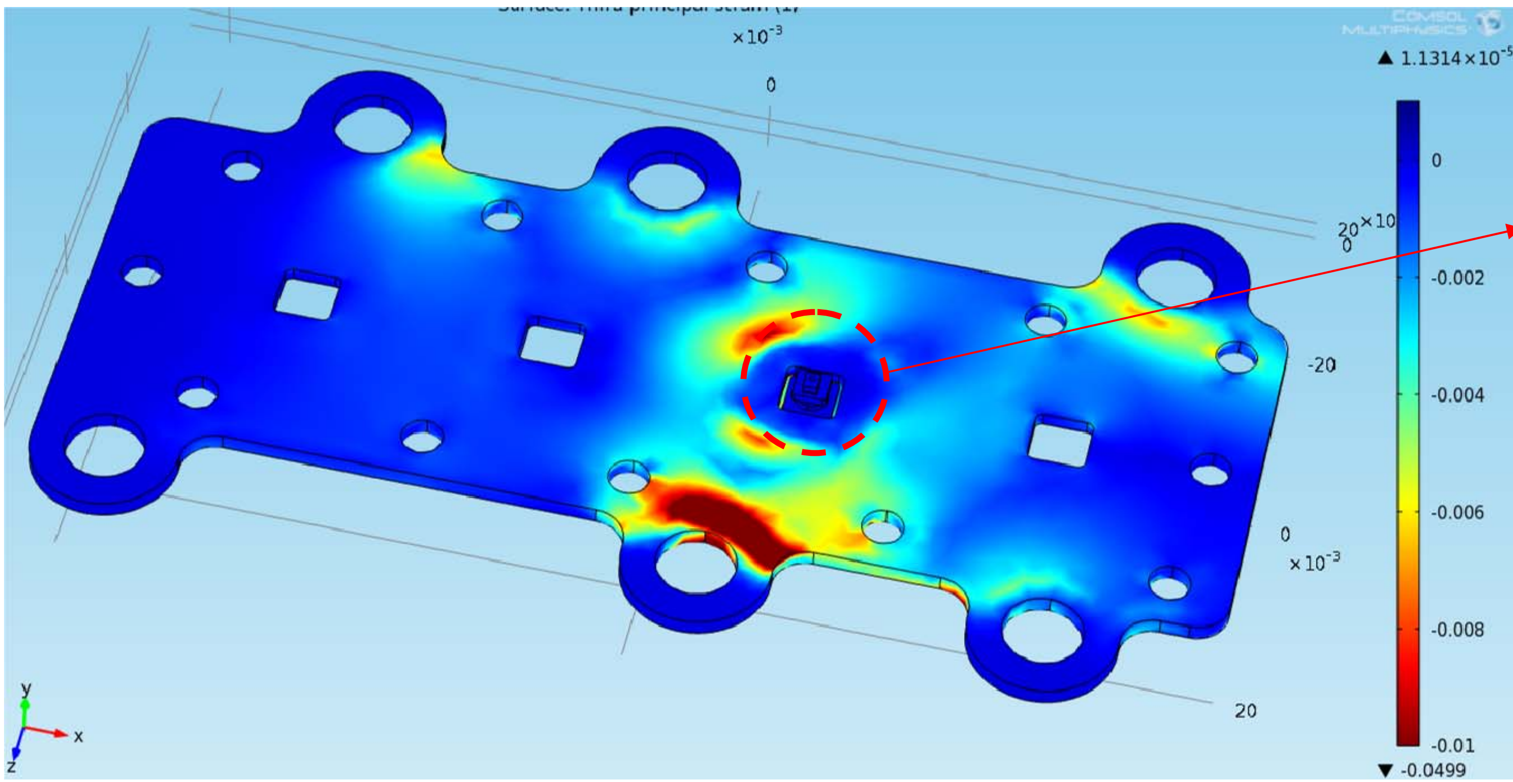
- Strain in MEMS adhesive up to 0.04 and will not last in thermal shock

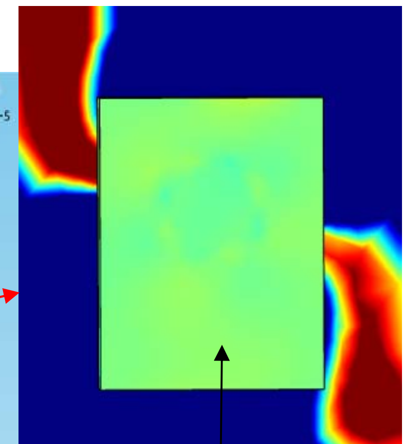
Max
0.04 strain
In adhesive



FEA of MEMS Mounted on Isolation Pedestal

- Predicted sensor error due to mounting < 0.05% of Sensor Span
- Correlation between theoretical and actual sensor data > 90%



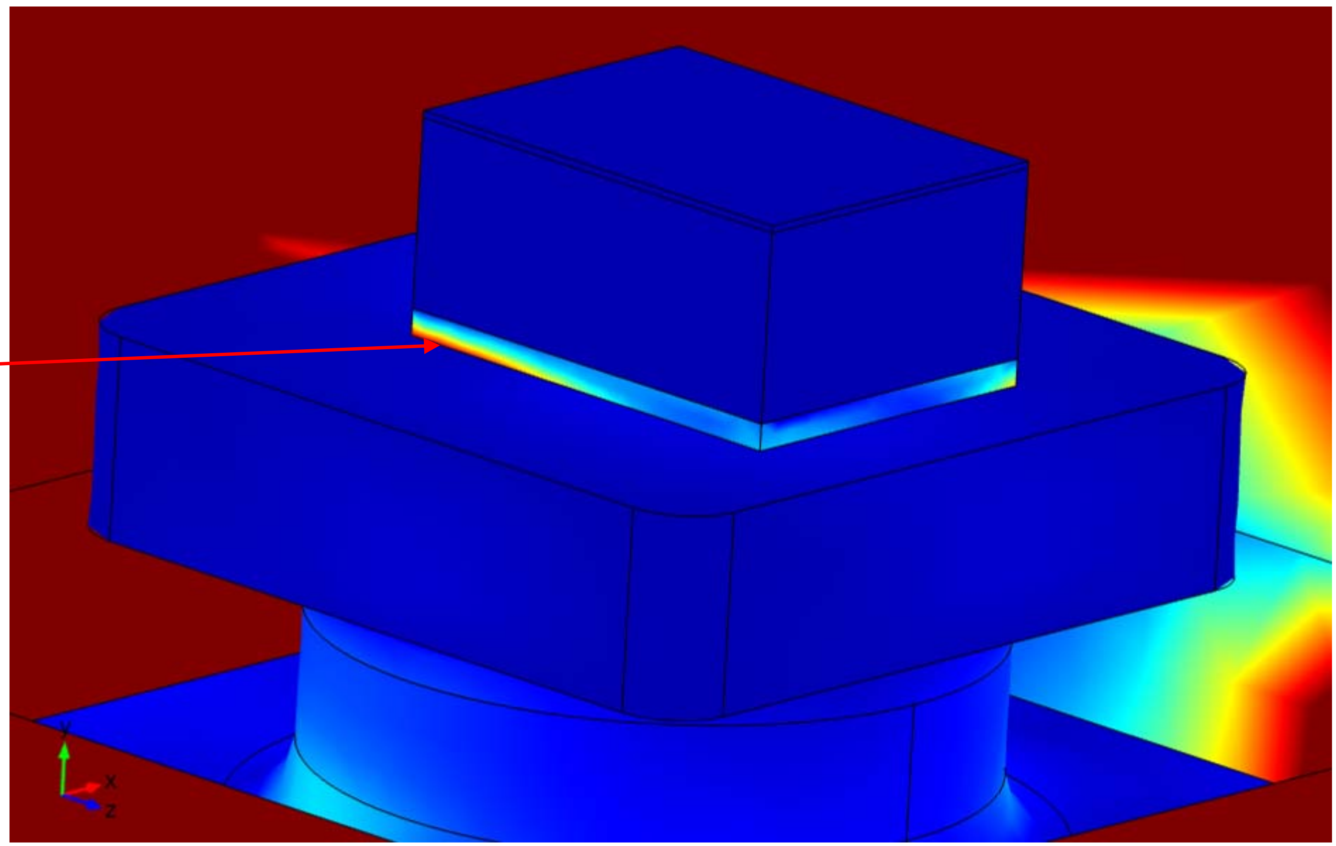


Max
0.1 μstrain
on MEMS
Die Surface

FEA of MEMS Mounted on Isolation Pedestal

- Strain in MEMS adhesive up to < 0.0002 and will be robust to environmental testing

Max Strain
< 0.0002
In Adhesive



Summary from Finite Element Analysis

- Isolation pedestal reduced undesired membrane surface strains to a negligible level when the sensor was mounted in application and no acceptable solution was found when mounting MEMS on metal base plate
- Strain in MEMS attachment adhesive was up to 0.04 and would have resulted in failure during thermal shock without isolation pedestal, with isolation pedestal strain was lowered to 0.0002
- High correlation between theoretical and experimental results
- FEA proved to be an effective means to model the sensor to develop a robust packaging solution prior to prototype
- Upon validation of model, it was used to optimize MEMS design for lowest cost

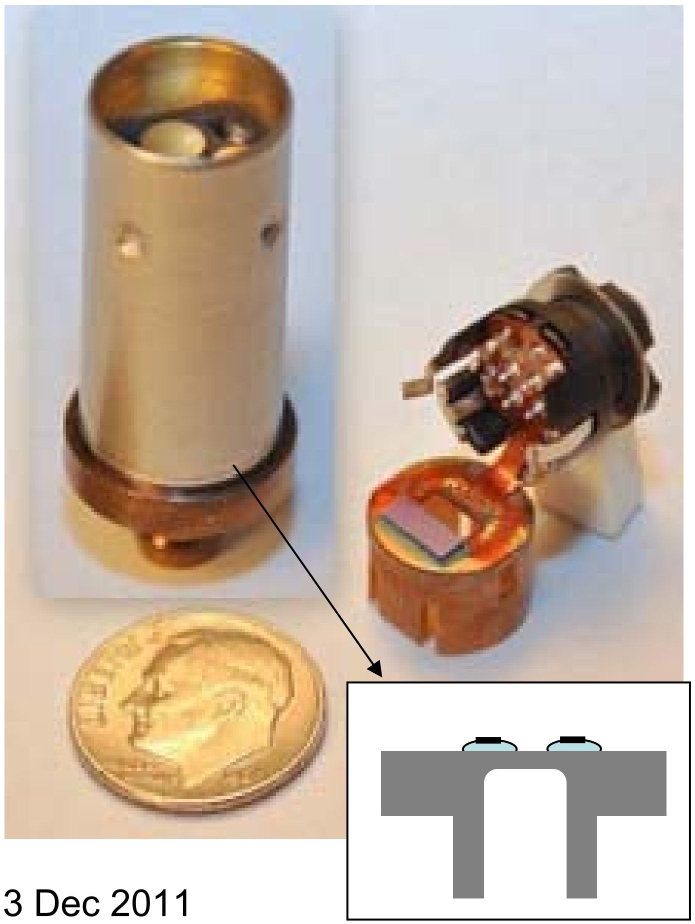
Conclusions

- It is important in MEMS sensor integration to always be mindful of output errors due to mounting sensitivity and thermal transients
- In high volume applications, lowest cost is achieved when the sensor package, foundry processes and MEMS sense element are designed concurrently
- Finite element analysis is an effective means to predict mounting sensitivity and find solutions for mitigation prior to prototype
- With proper modeling techniques, first pass functional sensors can accelerate system development for proof of concept to end user

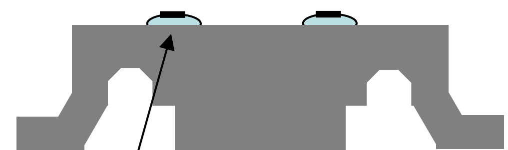
Questions?

MEMS in Automotive Sensor Applications

Brake Pressure Sensor for
Electronic Stability Control



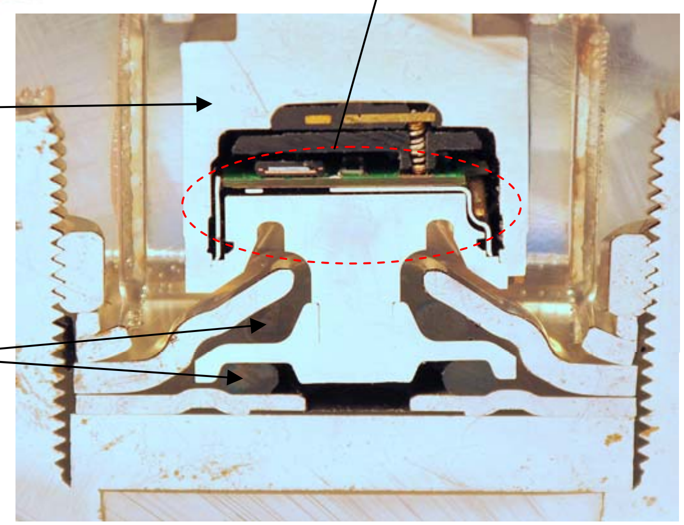
Occupant Weight Sensor
Passenger Airbag Deactivation



Microfused
MEMS Gages

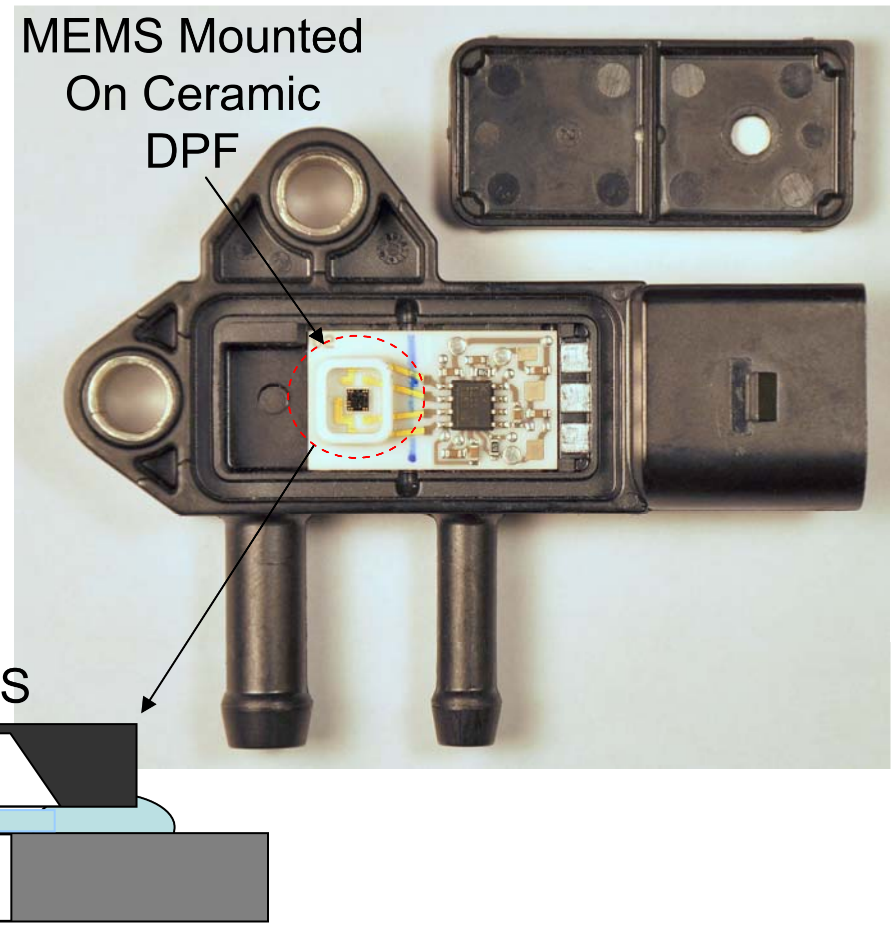
Sensor Body
Pivots as a
Joy Stick

O-rings
Top and Bottom
Of Disc



MEMS in Automotive Sensor Applications

- Differential Pressure Sensor Across Diesel Particulate Filter



MEMS in Automotive Sensor Applications

- Manifold Absolute Pressure (MAP) Sensor