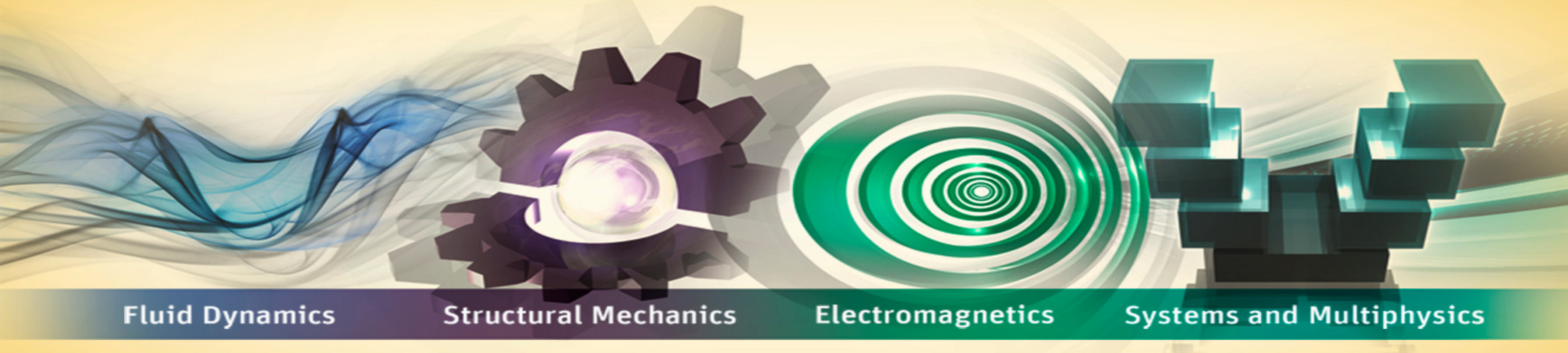
Realize Your Product Promise™

ANSYS Piezo-Electric and MEMS Solutions



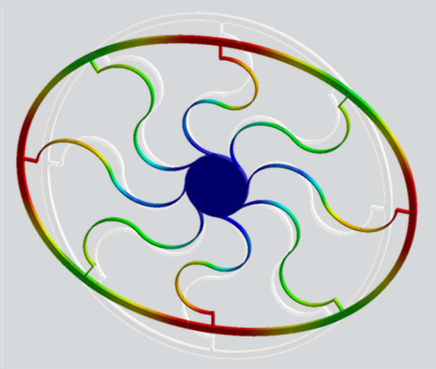
By:MingYao.Ding@Ansys.com

Agenda

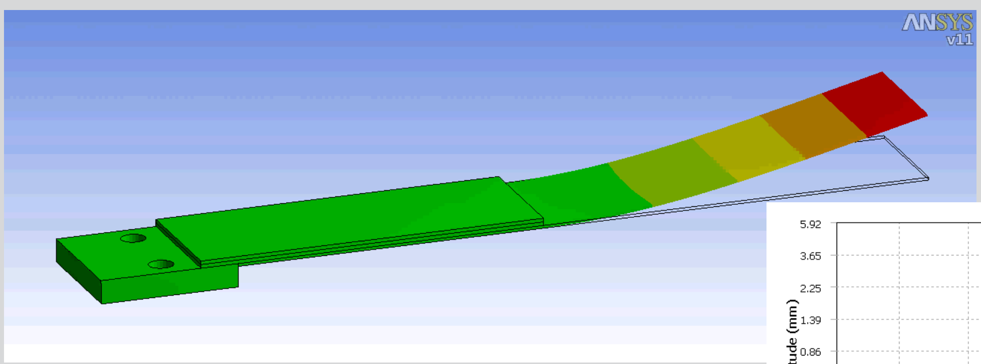
- **Background**
  - MEMS devices
  - ANSYS Piezoelectric and MEMS Capabilities
- **ANSYS MEMS workflows**
  - Geometry import
  - ANSYS Piezoelectric and MEMS ACT extension
- **Examples**
  - Piezoresistive pressure sensors
  - Surface acoustic wave resonators
  - Gyroscope

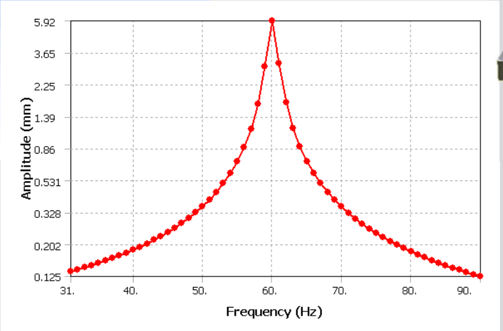
MEMS devices

- **MicroElectromechanical Systems (MEMS) - also is called micromachines and microsystems in Asia and Europe.**
- **Made with semiconductor construction techniques, these devices have tiny parts measured in microns (millionths of a meter) and are frequently combined with integrated circuits on a single chip to provide built-in intelligence and signal processing.**

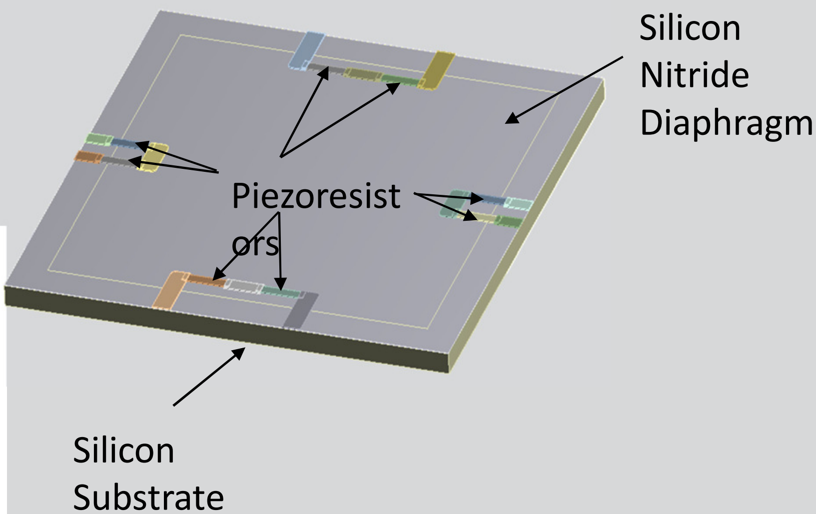


Silicon Ring Gyroscope – Harmonic response including thermoelastic damping solved with direct coupled-field elements.

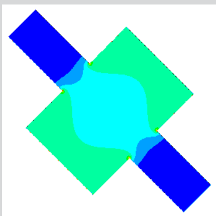


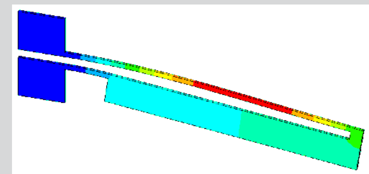


Piezoelectric Fan

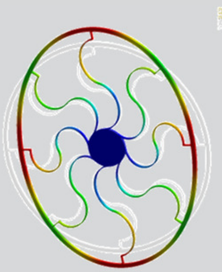


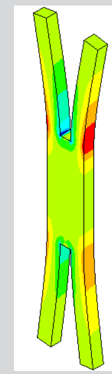
ANSYS Piezoelectric and MEMS Capabilities

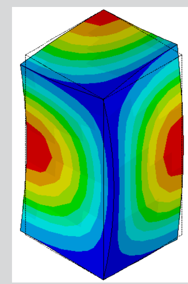




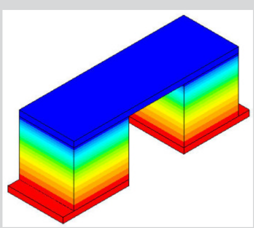
- **Piezoelectric**
  - transducers, resonators, sensors and actuators, vibration control, accelerometers
- **Piezoresistive**
  - pressure sensors, strain gauges, accelerometers

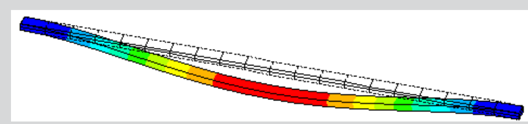






- **Thermal-electric**
  - wires, busbars, Peltier coolers, thermo-generators
- **Thermoelastic damping**
  - MEMS resonators





- **Electrostatic-structural**
  - actuators
- **Coriolis effect**
  - quartz angular velocity sensors

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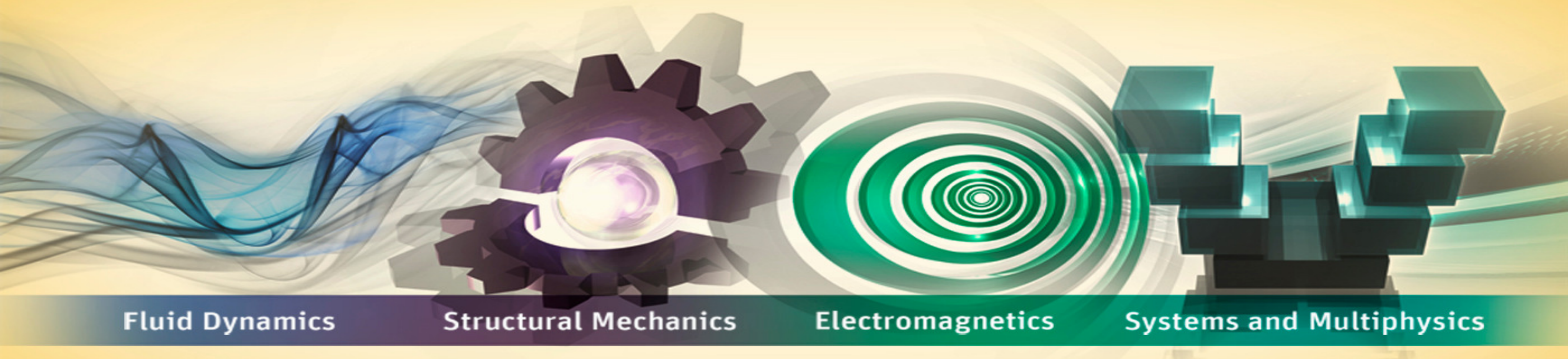
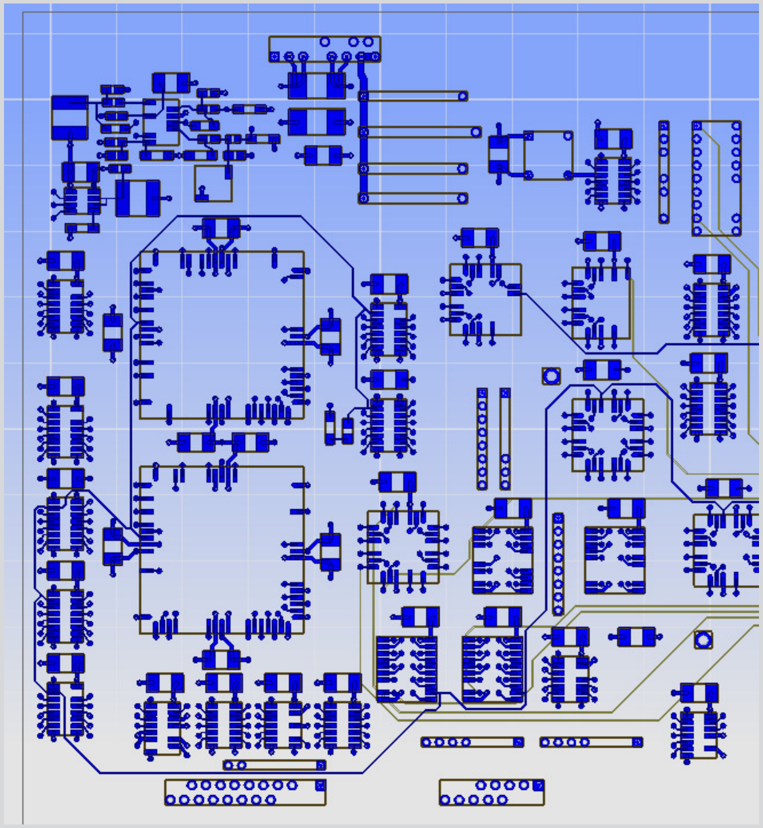
Workflow



Geometry import

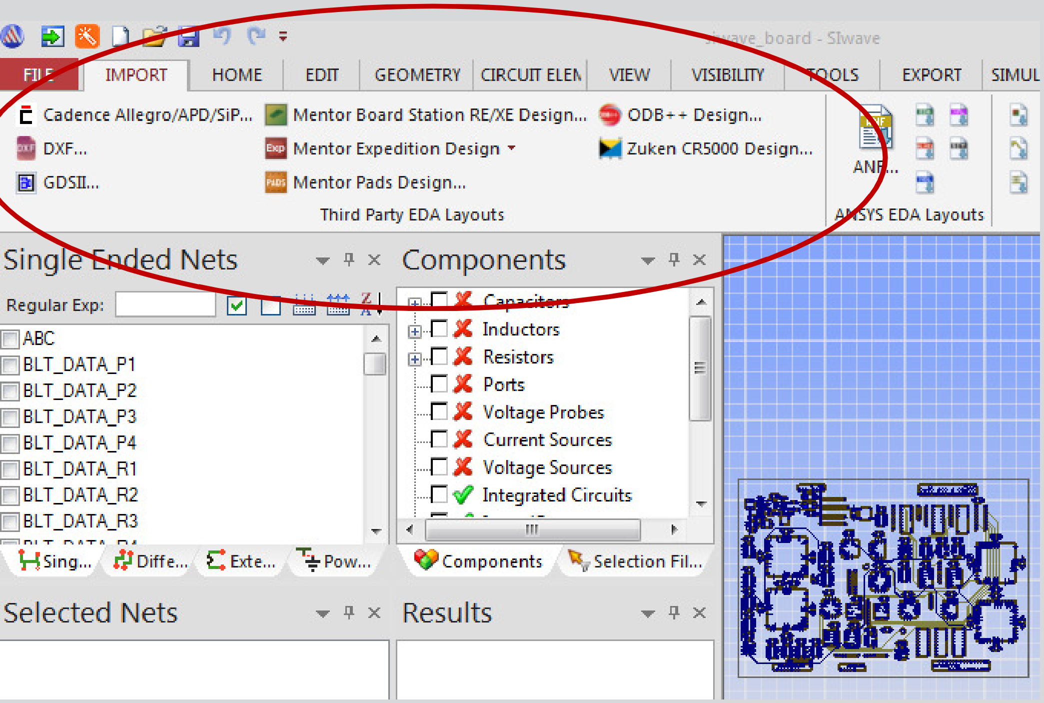
- **MEMS devices are typically designed as 2D layout.**
- **To run a simulation, this 2D layout usually need to be converted into a 3D solid model.**

- **Current ANSYS Options**
  - Alinks
  - Spaceclaim

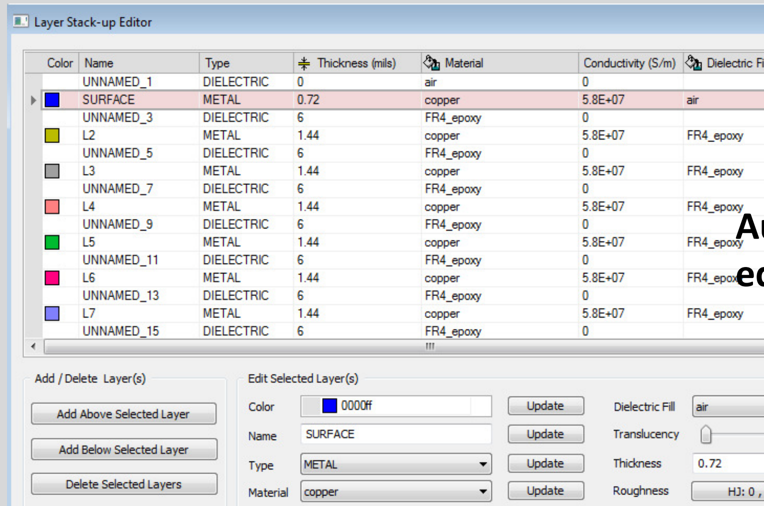


2D ECAD Layout

Alinks – Formerly called Ansoft Links



Alinks import options

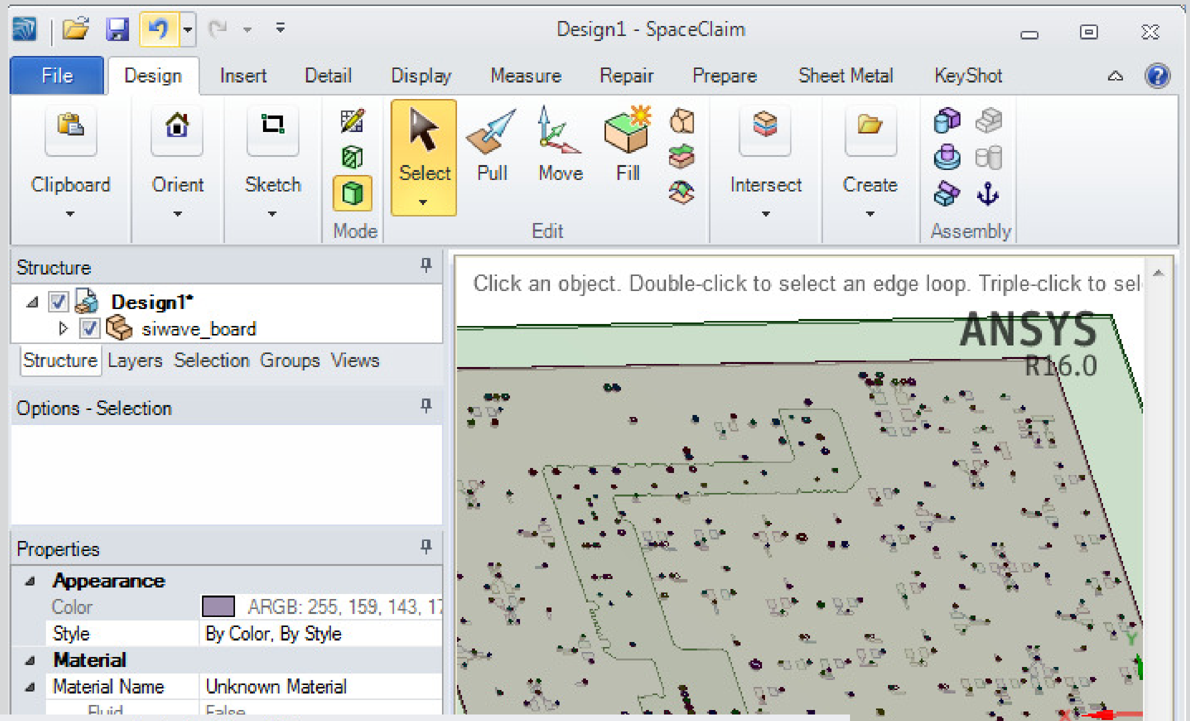


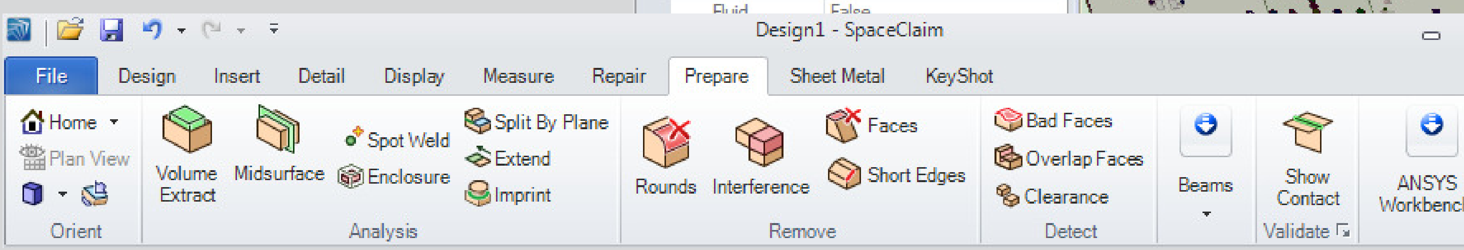
Automatic stack-up editor

3D geometry created

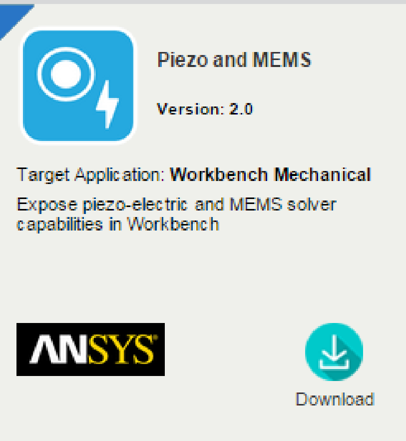
ANSYS SpaceClaim

- **ANSYS SpaceClaim is a CAD preparation tool**
  - Intuitive
  - Easy to use
  - Powerful
- Support layout formats such as
  - DXF and DWG
  - Idf, idb and emn formats
- Supports many powerful simulation preparation capabilities

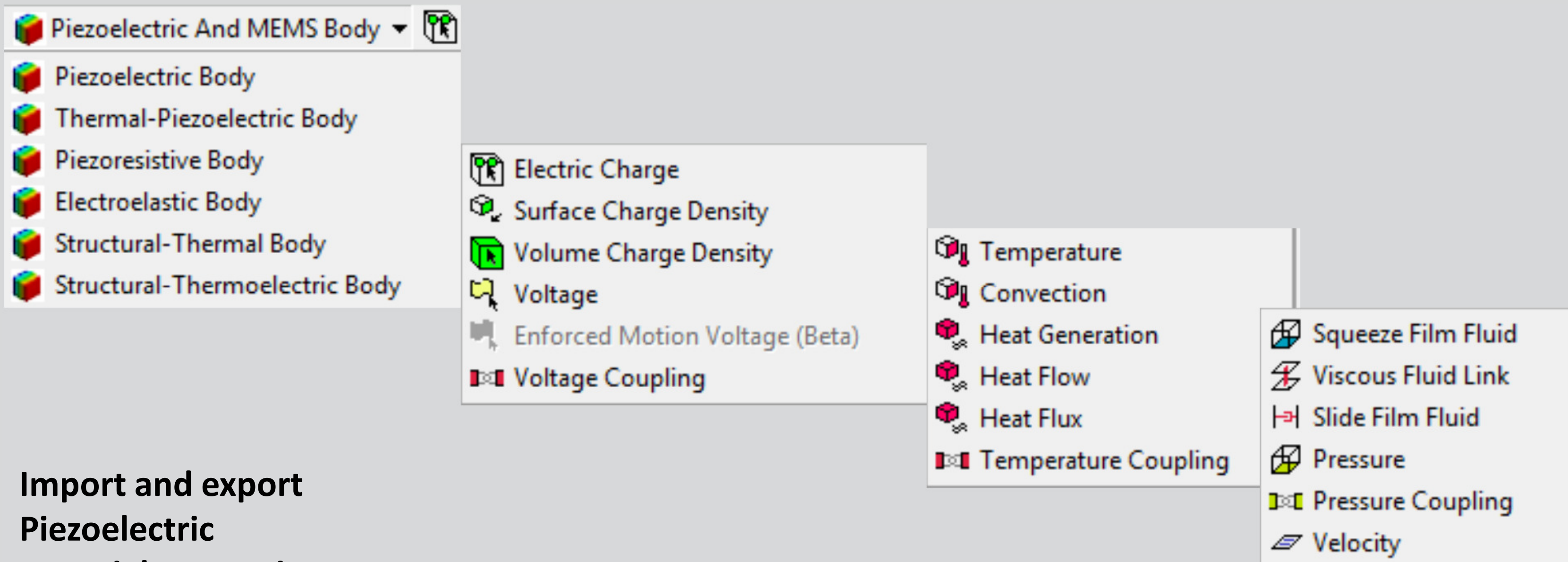


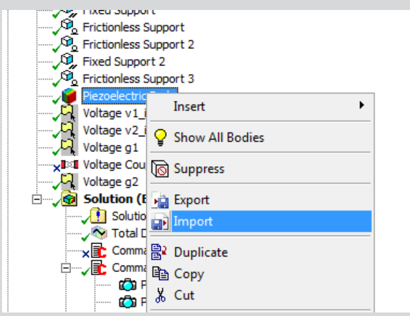


ANSYS Piezoelectric and MEMS Extension



- **Download from the customer portal under Downloads>Application Library**
- **Free!**





Import and export Piezoelectric material properties

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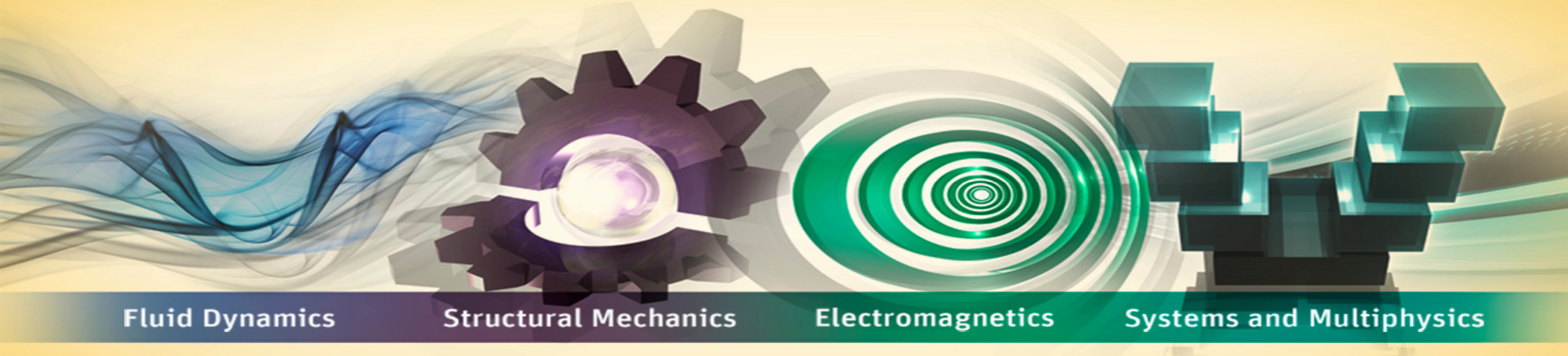
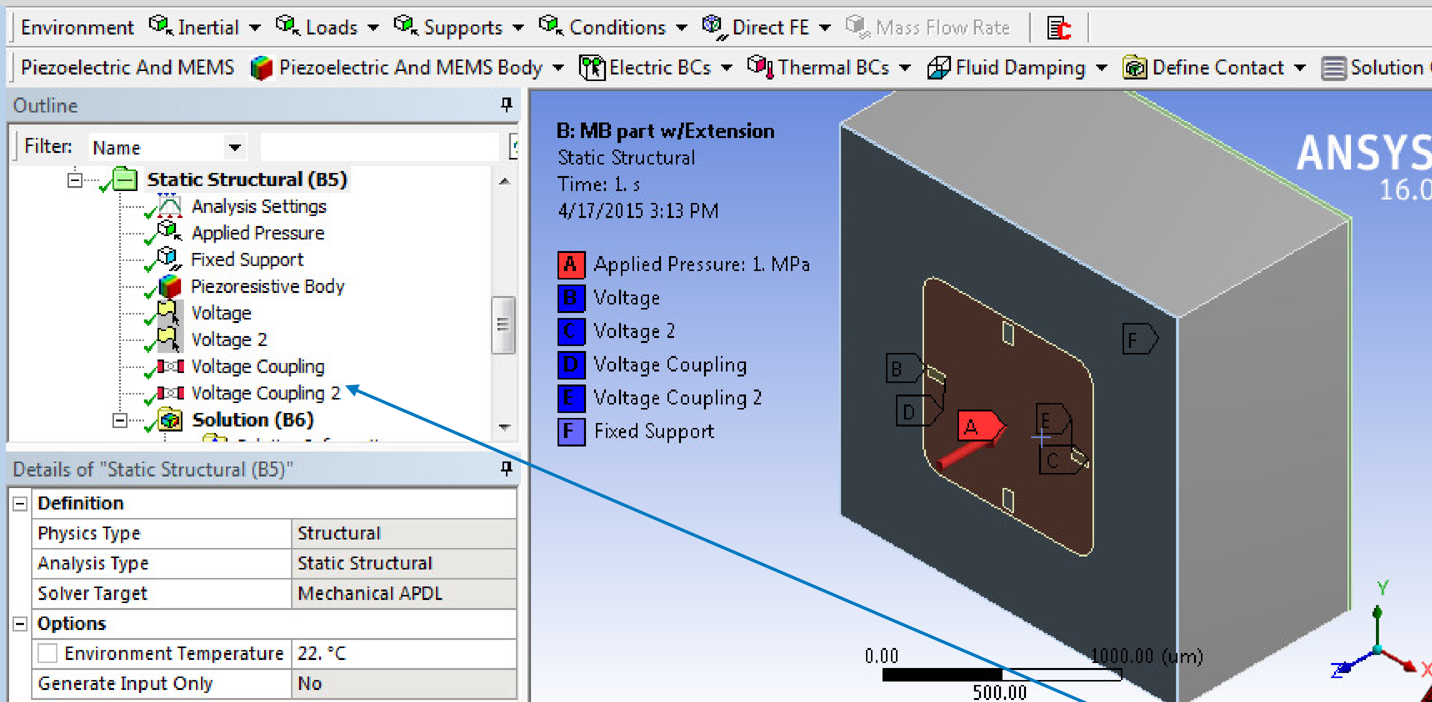
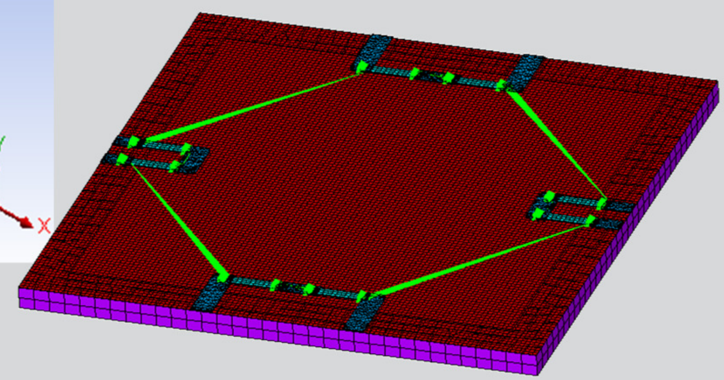
Example Pressure Sensor



Piezoresistive Pressure Sensor Setup

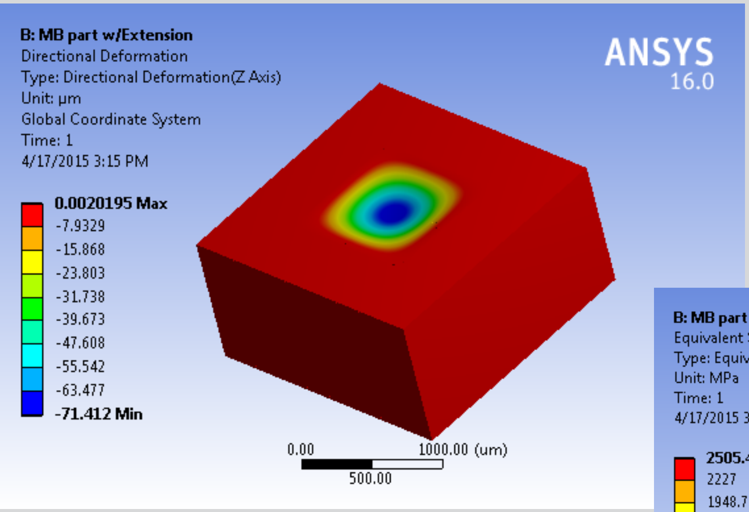




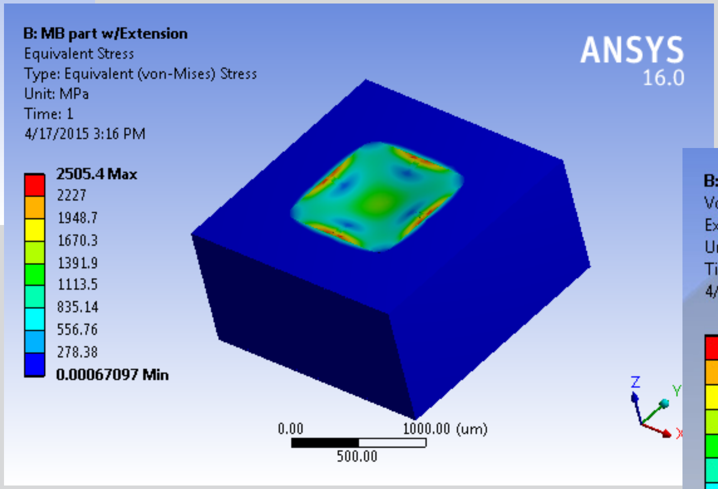
Voltage Coupling to create Wheatstone Bridge Circuit

Results

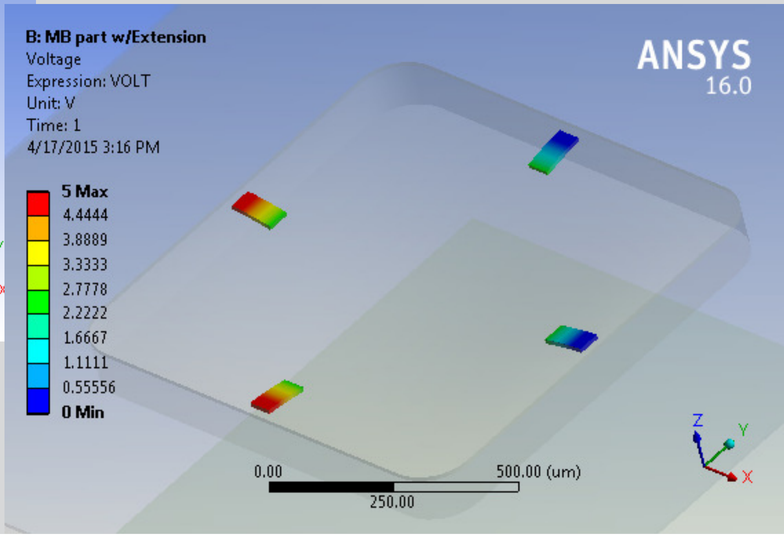
Deformation



Stress



Voltage



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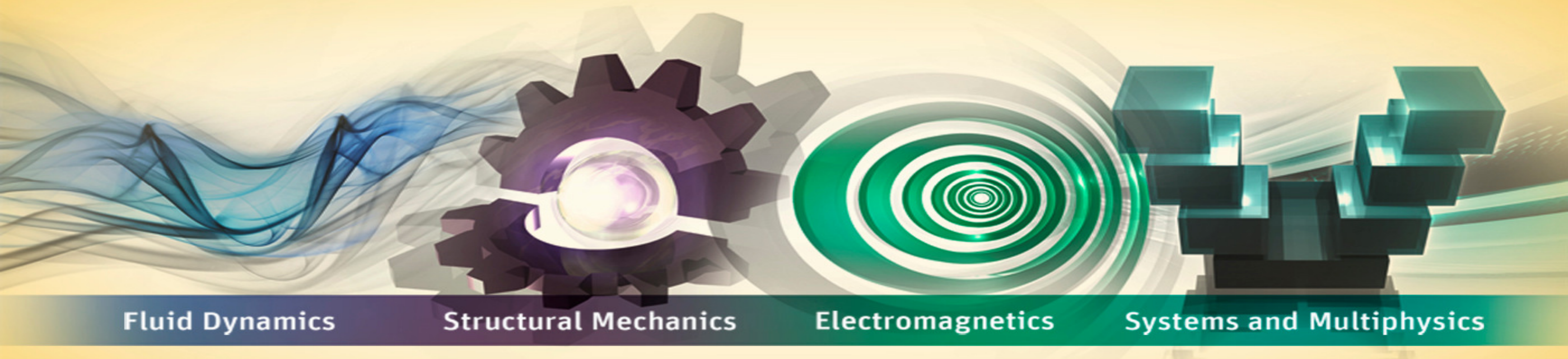
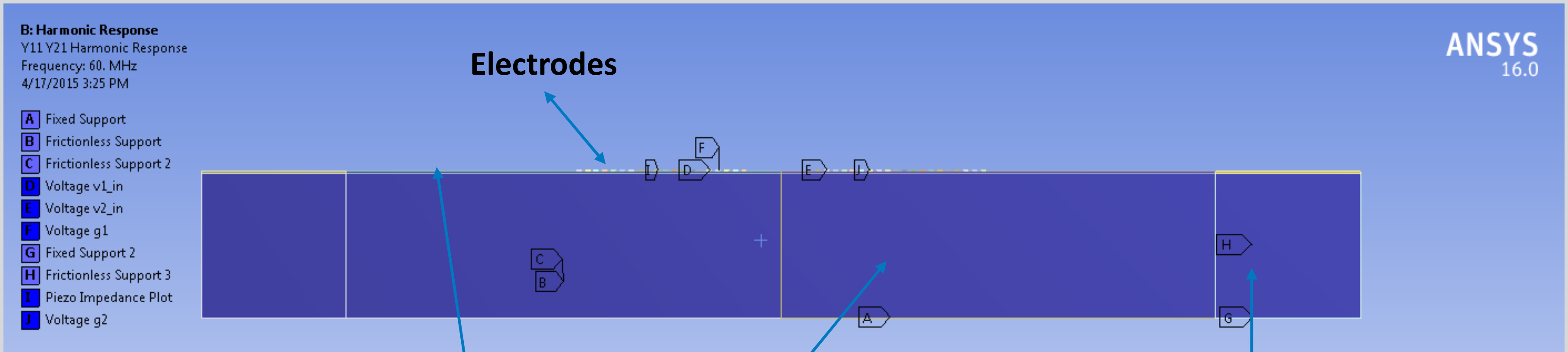
Example Surface Acoustic Wave Resonator



Surface Acoustic Wave Resonator

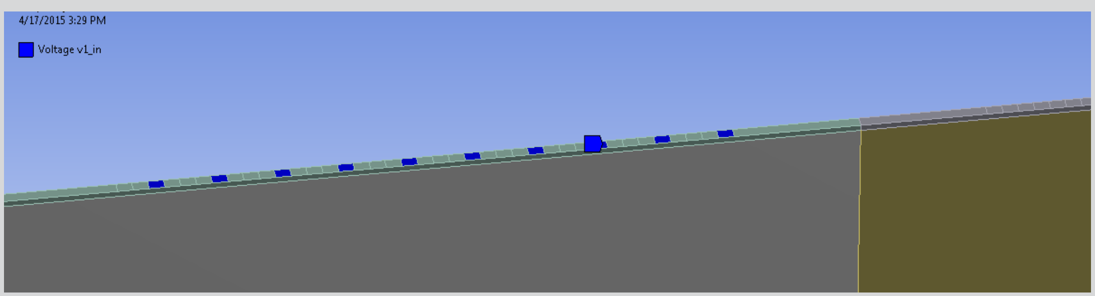


Thin Piezoelectric Layer

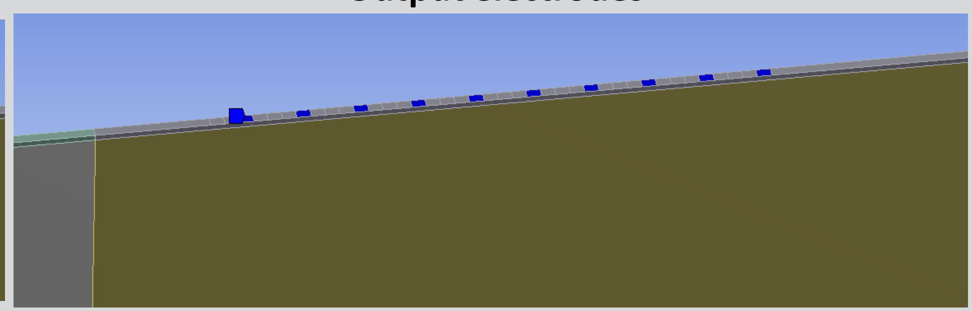
Silicon Base

Vibration absorption region

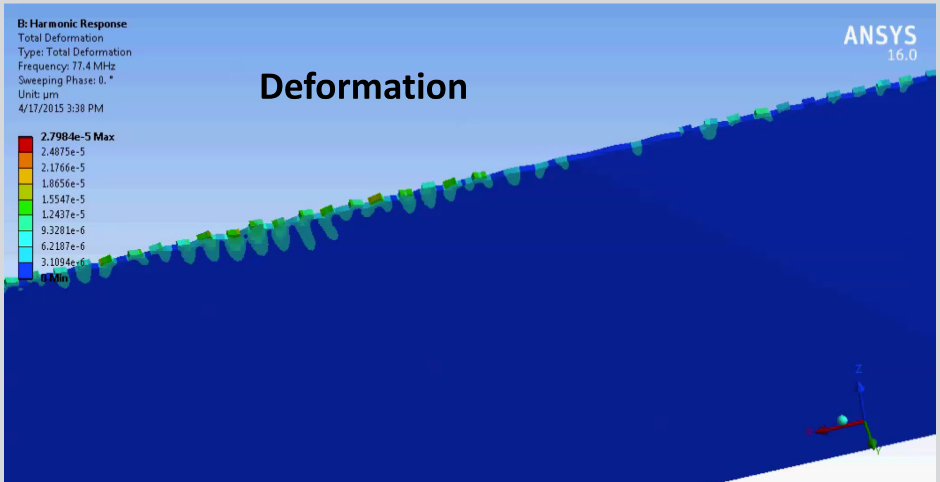
Input Electrodes

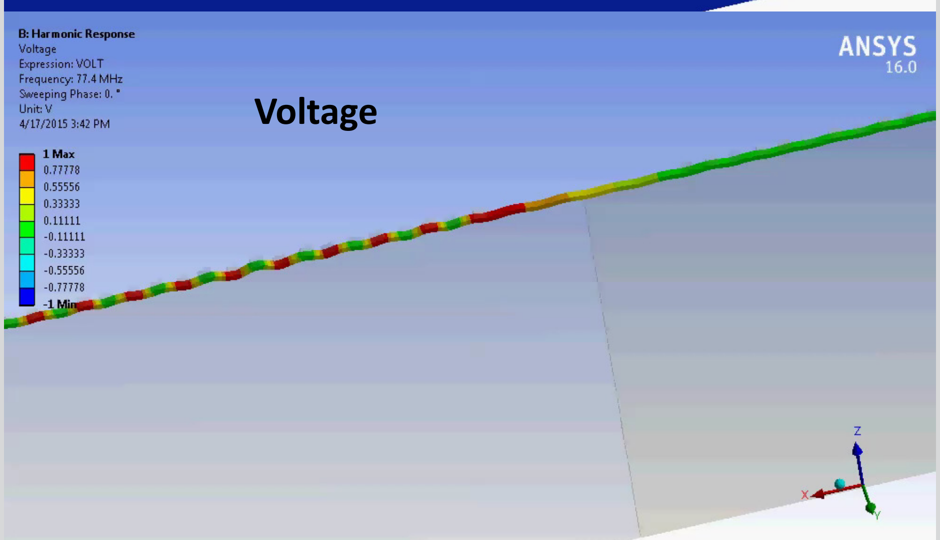


Output electrodes

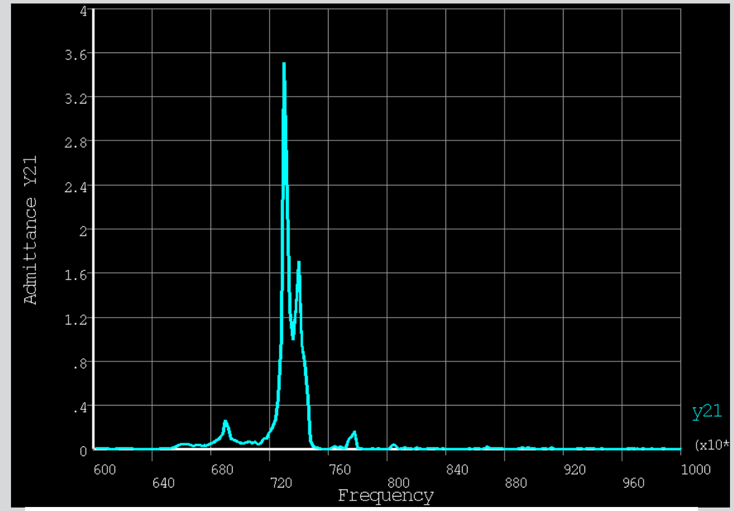


Results

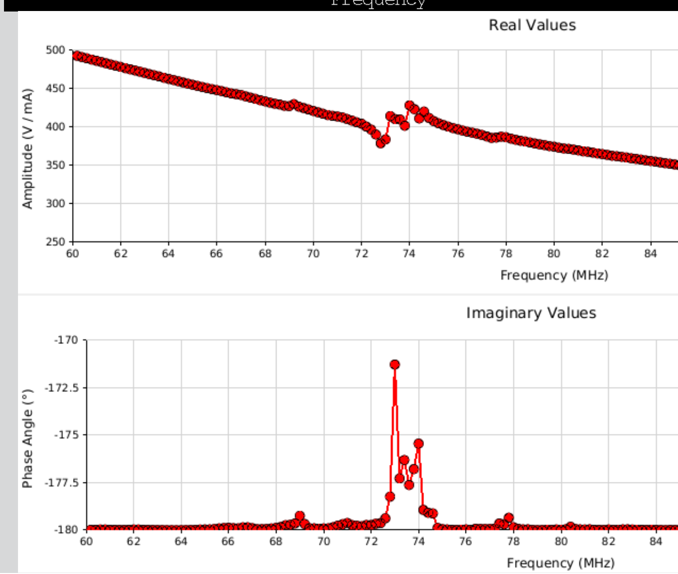




Admittance



Impedance

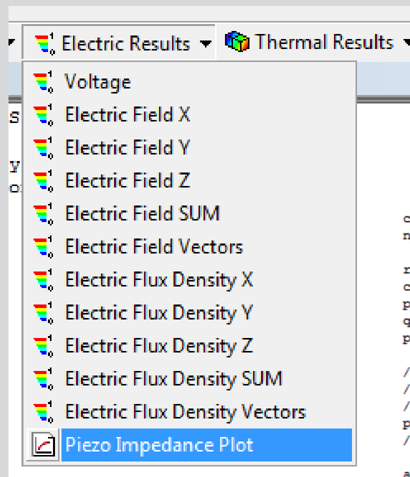


New Capabilities

- **New in ANSYS R16 Perfectly Matched Layers for Structural Element.**
  - Currently limited to isotropic elements
  - R17 - expected to be applicable to Piezoelectric elements as well
- Piezo Impedance Plot post processing available for 1 port system.
- Multiport impedance/admittance plots can be generated using APDL commands.

5.1.6. Perfectly Matched Layers (PML) for Structural Elements

Perfectly matched layers (PML) are artificial anisotropic materials that absorb all incoming elastic waves without any reflections to make the infinite elastic wave propagating domain into the finite numerical simulation domain for a harmonic analysis. PML are also used to truncate the infinite domain for a static solution. PML are defined by the SOLID185, SOLID186, and SOLID187 elements with KEYOPT(15) = 1.




```
cmsel,s,v2_in                ! SELECT OUTPUT ELECTRODE NODES
n_Pos=ndnext(0)              ! FIRST NODE IN SELECTED SET

rforc,6,n_Pos,chrg           ! VARIABLE 6: CHARGE Q2 AT CONSTRAINED MASTER NODE OF CP SET
cfact,0,2*acos(-1)           ! FACTOR FOR "IA" VARIABLE IN SUBSEQUENT OPERATION: 0 + j*2*pi
prod,7,1,6,,current_pos      ! VARIABLE 7: CURRENT i2 = jwQ2
quot,8,7,3,,y21              ! VARIABLE 8: Y21 = i2/V1
prvar,1,5,8

/sho,png                     ! PLOT Y21{f}
/axl,x,Frequency
/axl,y,Admittance Y21
plva,8
/sho,close

allsel,all
```

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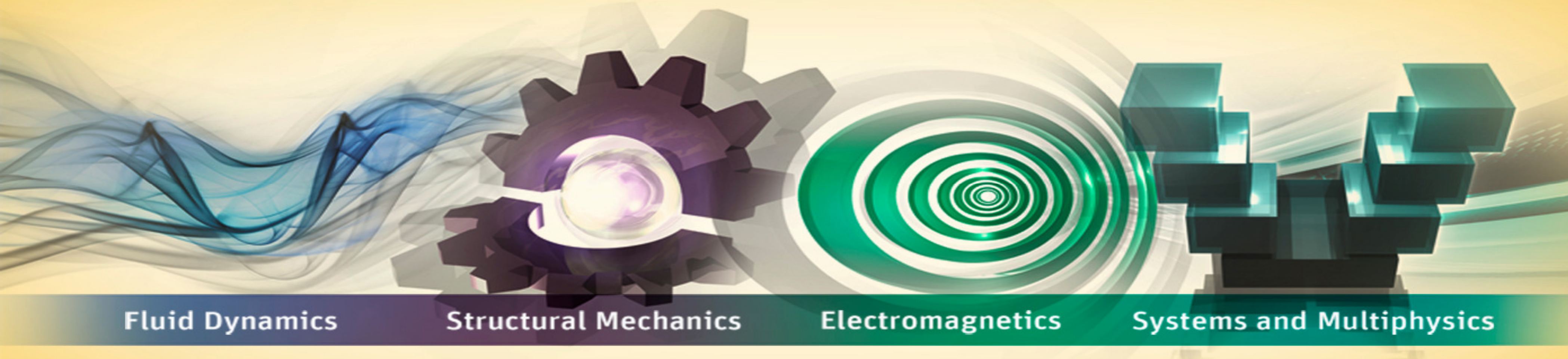
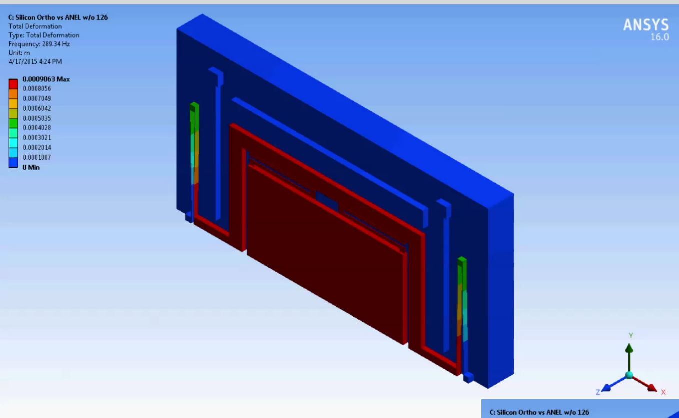
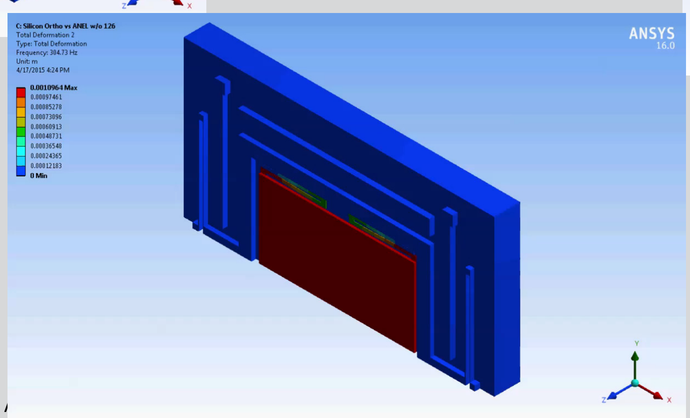
Example Gyroscope

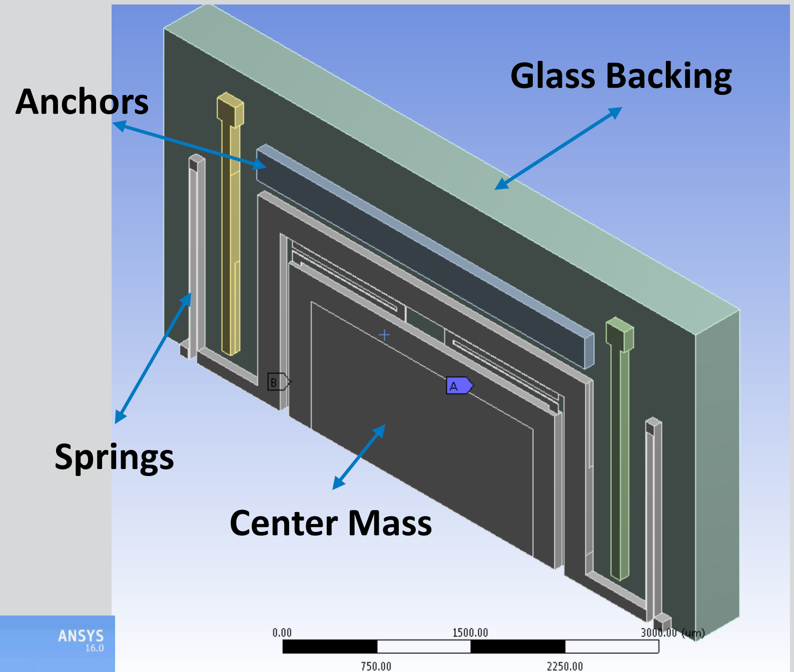


Gyroscope

- **Start with basic modal analysis to calculate the resonant frequencies**

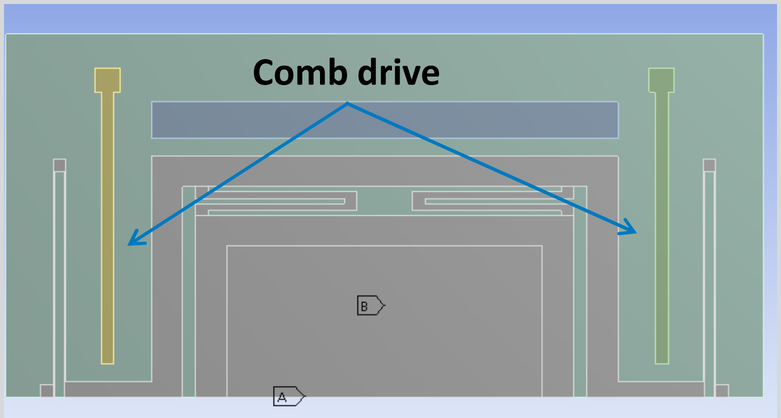


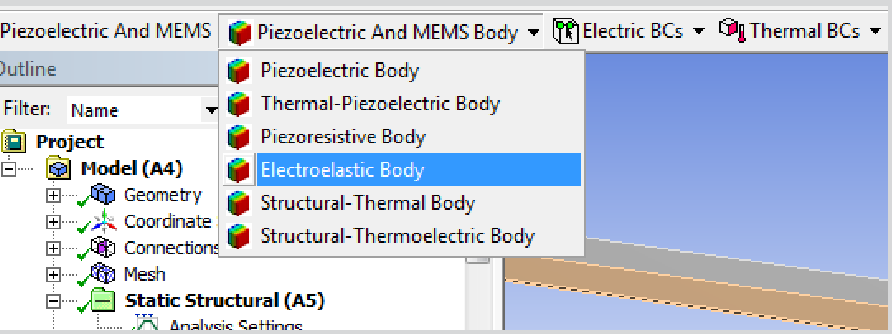




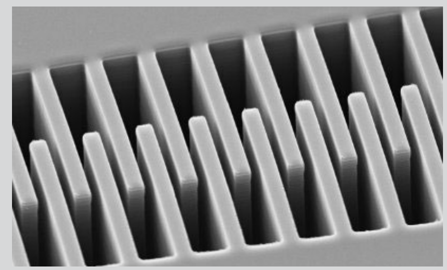
Mode	Frequency [Hz]
1.	289.34
2.	304.73
3.	328.71
4.	2832.
5.	4920.8
6.	6444.9

Gyroscopes are often driven by electrostatic forces

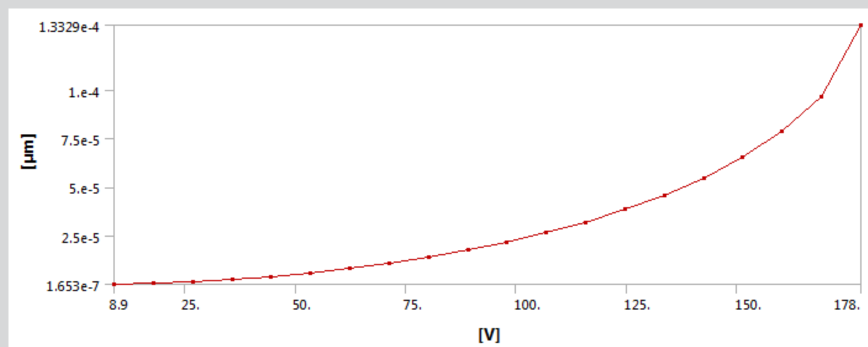




- Electrostatic voltage deflection behavior of the comb drive can characterized using the Piezoelectric and MEMS extension in ANSYS Mechanical
- Electroelastic body will have other electrical and structural degrees of freedom and is used here to model the air gap.

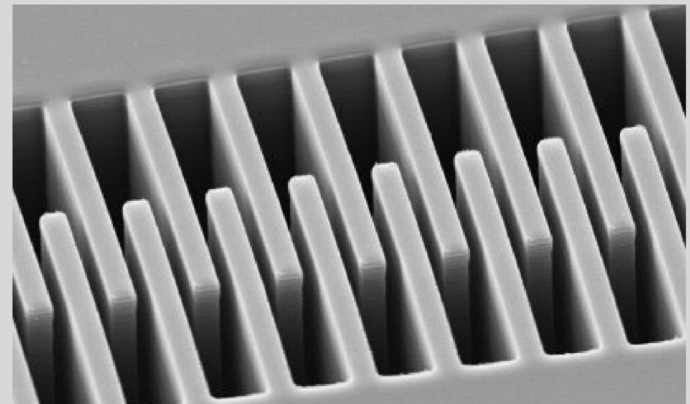


Comb Drive



Electromechanical transducers

- Comb drives are geometrically complex and repetitive.
- Once characterized, they can be represented in ANSYS as electromechanical transducer elements
- These elements can be generated using a command script.

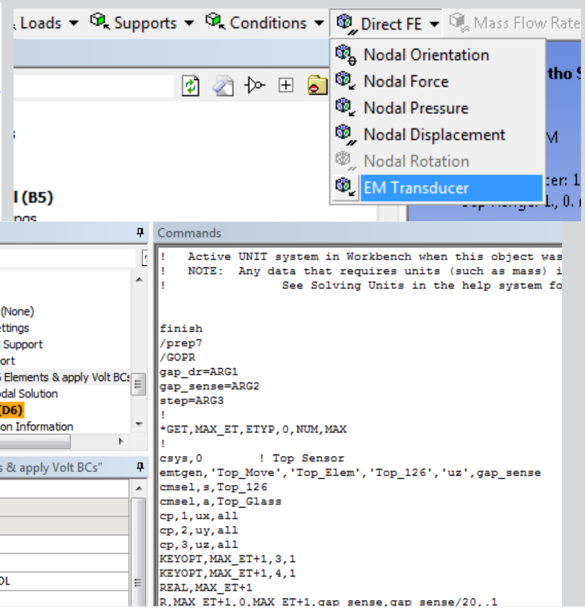


Electromechanical Transducer

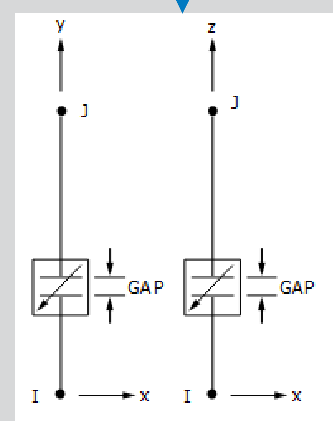
MP <> <> <> <> <> <> <> PP EME <>
Product Restrictions

TRANS126 Element Description

TRANS126 represents a transducer element that converts energy from an electrostatic domain into a structural domain (and vice versa), while also allowing for energy storage. The element fully couples the electromechanical domains and represents a reduced-order model suitable for use in structural finite element analysis as well as electromechanical circuit simul… element has up to two degrees of freedom at each node: translation in the nodal … direction and electric potential (VOLT). The element is suitable for simulating the … electromechanical response of micro-electromechanical devices (MEMS) such as … comb drives, capacitive transducers, and RF switches for example.

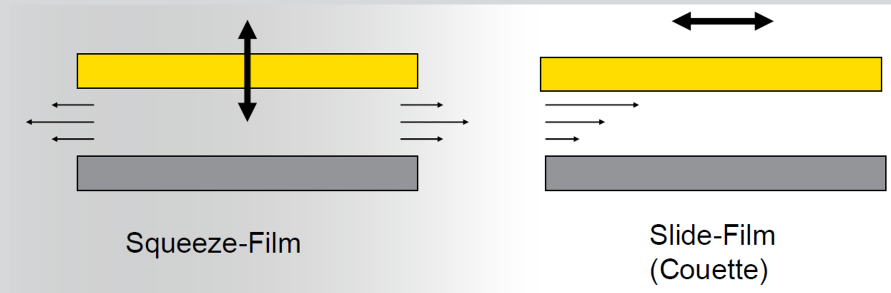


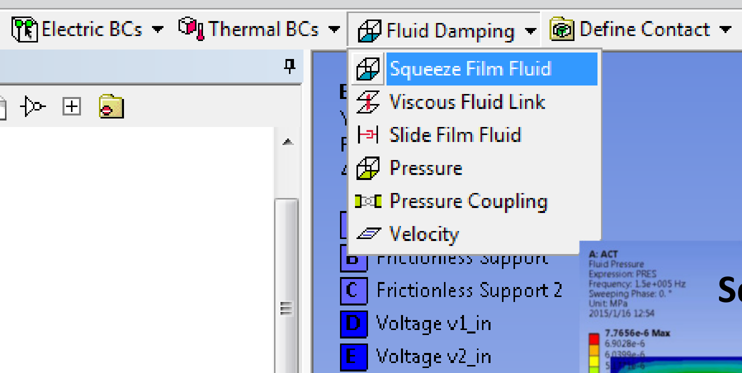

```
!   Active UNIT system in Workbench when this object was
!   NOTE:  Any data that requires units (such as mass) i
!                  See Solving Units in the help system fo


finish
/prep7
/GOPR
gap_dr=ARG1
gap_sense=ARG2
step=ARG3
!
*GET,MAX_ET,ETYP,0,NUM,MAX
!
csys,0          ! Top Sensor
emtgen,'Top_Move','Top_Elem','Top_126','uz',gap_sense
cmsel,s,Top_126
cmsel,a,Top_Glass
cp,1,ux,all
cp,2,uy,all
cp,3,uz,all
KEYOPT,MAX_ET+1,3,1
KEYOPT,MAX_ET+1,4,1
REAL,MAX_ET+1
R,MAX_ET+1,0,MAX_ET+1,gap_sense,gap_sense/20,.1
```



Damping

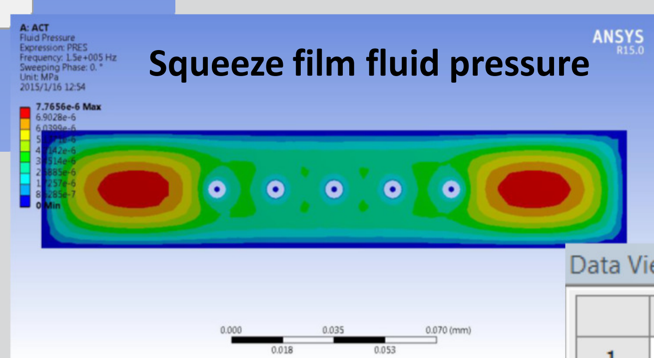
- **The motion of the large center mass results in significant fluid damping.**
- **Fluid damping models are available in the Piezoelectric and MEMS extension**





Viscous Link Element – Fluid138

- **Models the viscous fluid flow behavior through short channels (holes) moving perpendicular to fixed surfaces.**



Extracted equivalent stiffness and damping

Data View

	Frequency [Hz]	Equivalent Stiffness [N mm^-1]	Equivalent Stiffness [N mm^-1 s]
1	50000.0	6.11604e-05	1.33663e-08
2	100000.0	0.000244452	1.33571e-08
3	150000.0	0.00054931	1.33419e-08

More Damping

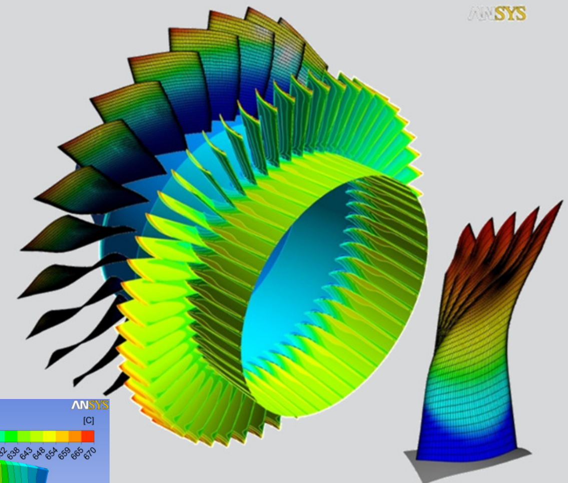
- **Fluid damping can also be modeled using ANSYS CFD tools.**
- **Developed for turbo machinery applications, but can be used for any geometry.**
- **Also support forced response**
  - Export complex pressure from CFD simulation for load application in Mechanical Harmonic simulations

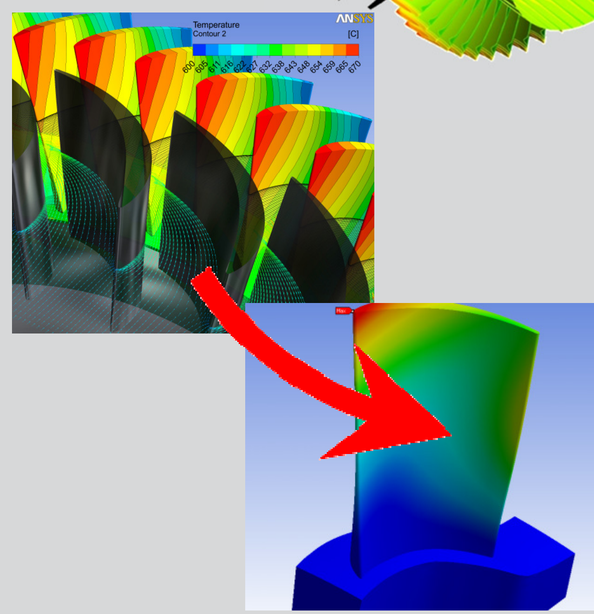
Mechanical →
- Set up modal analysis as usual
- Export mode shape and parameters

CFX-Pre →
- (Expand Profile)
- Import profile
  - Note parameter values
  - Verify profile geometry and data
- Enable mesh motion
- Specify additional output for Pressure Work and Power

CFX Solver →
- Monitor Pressure Work/Power
- Integrates Pressure Work/Power over mode period

CFD-Post
- Visualize results
  - Displacements
  - Pressure Work/Power per unit area on blade surface
- Compute damping factor





Thank You!

- **We at ANSYS are working hard to make Piezoelectric and MEMS simulations more accurate and easier to use.**
- **If you have questions of suggestions please contact me at mingyao.ding@ansys.com**

