



# DESIGN AND SIMULATION OF A MEMS-BASED CMUT FOR VISCOSITY SENSING APPLICATIONS AND

DIVYA MOHAN YADAV  
RAHUL GOYAL

COMSOL  
CONFERENCE  
2018 BANGALORE

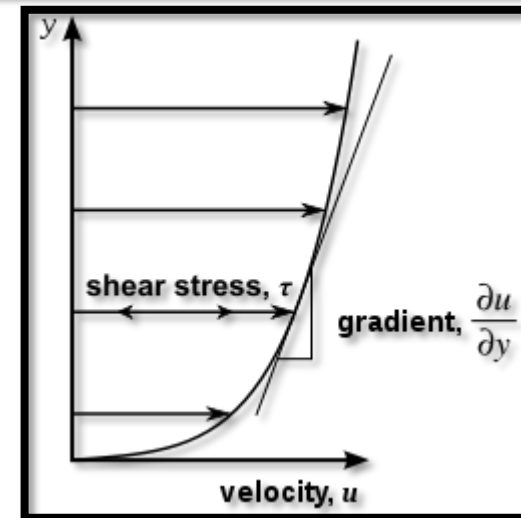
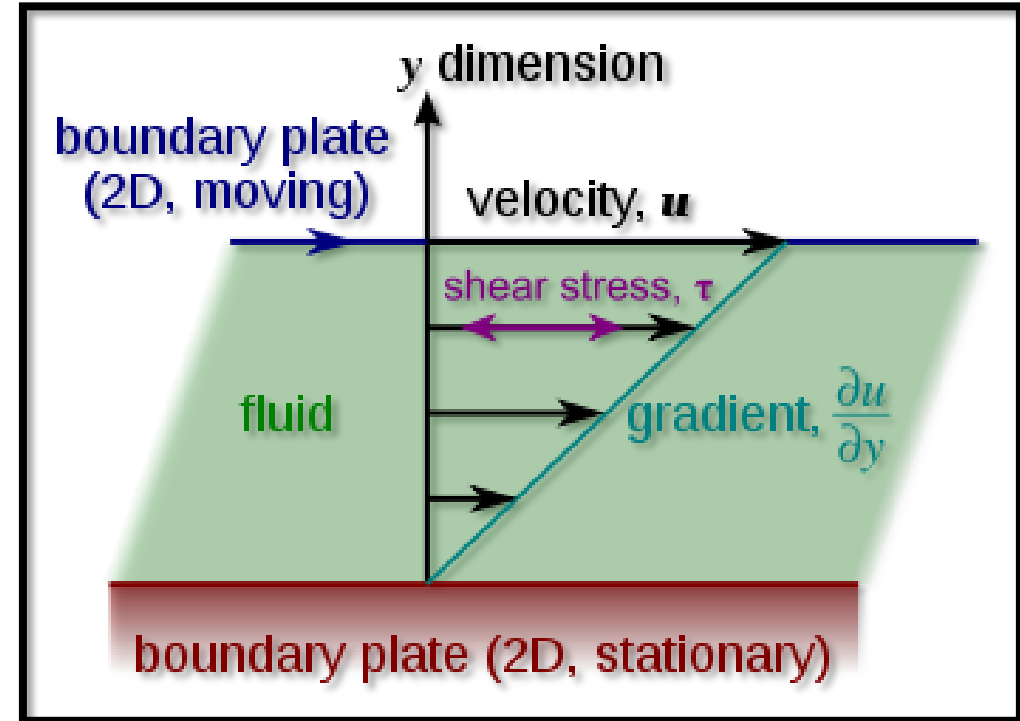
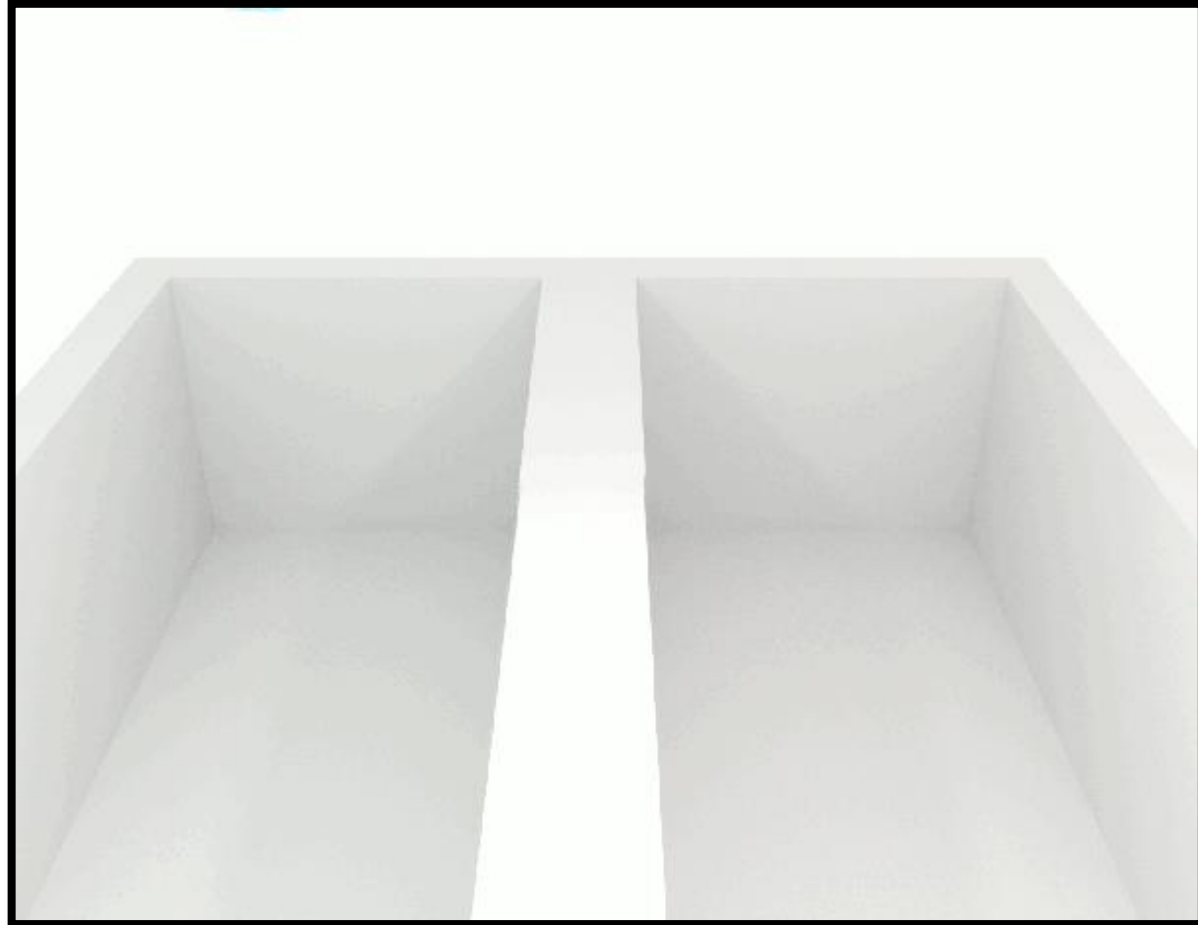


# OUTLINE



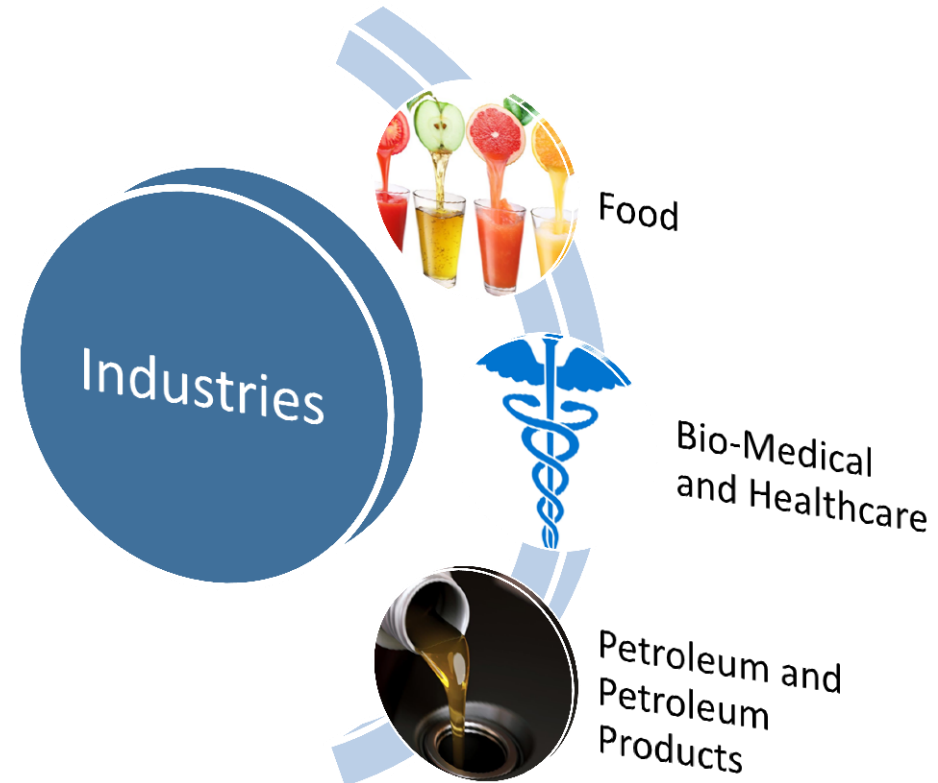
1. Viscosity and why sensing it is important
2. Need for MEMS viscometer
3. Novel idea of the viscosity sensor
4. Working of the sensor
5. Simulation of sensor using COMSOL
6. Results

# VISCOSITY



# WHY VISCOSITY MEASUREMENT IS IMPORTANT?

- Predict material behavior.
- Helps design transportation and processing parameters.
- Set standards for Quality Control.
- Correlate liquid composition.

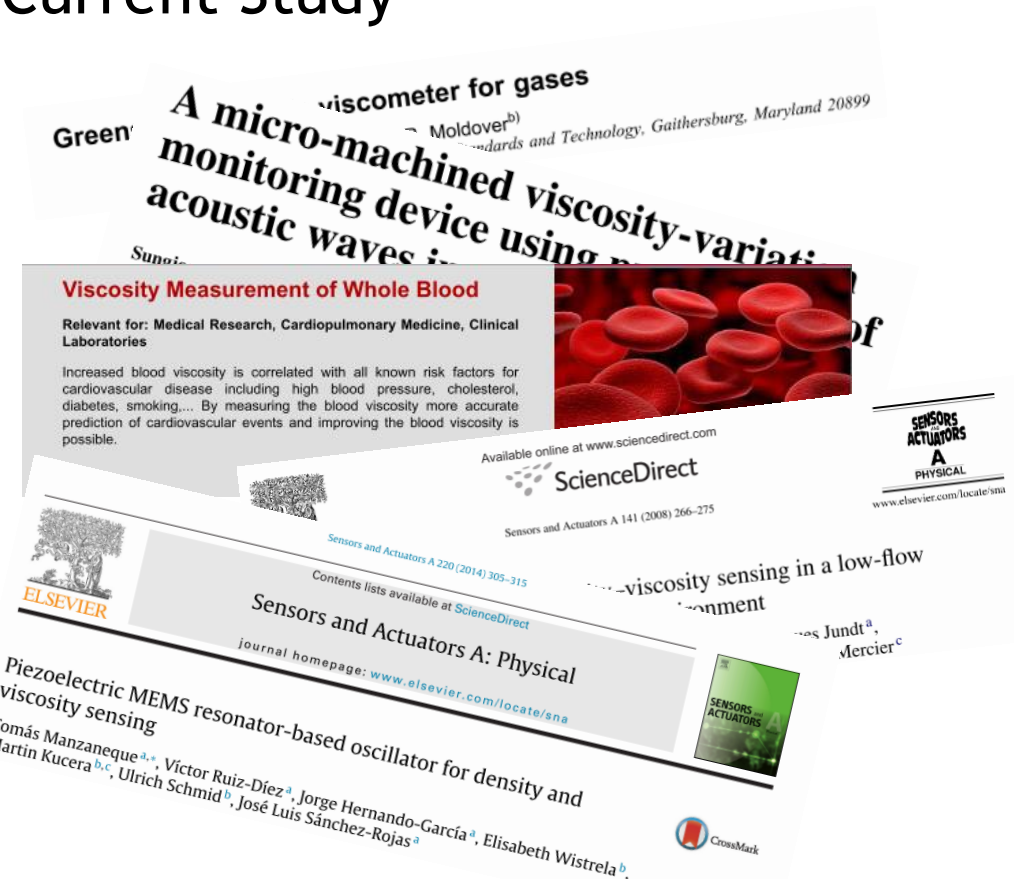


# WHY MEMS VISCOMETER?

Conventional Viscometers are:

- Slow
- Bulky
- Costly
- Require Human Intervention
- Not suitable for Inline measurements
- **Though have become more sophisticated with time.**

Current Study



**A micro-machined viscosity-variable acoustic waves sensor for gases**  
Green<sup>a</sup>, Moldover<sup>b</sup>  
<sup>a</sup>Standards and Technology, Gaithersburg, Maryland 20899

**Viscosity Measurement of Whole Blood**  
Relevant for: Medical Research, Cardiopulmonary Medicine, Clinical Laboratories  
Increased blood viscosity is correlated with all known risk factors for cardiovascular disease including high blood pressure, cholesterol, diabetes, smoking.... By measuring the blood viscosity more accurate prediction of cardiovascular events and improving the blood viscosity is possible.

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)  
ScienceDirect  
Sensors and Actuators A 141 (2008) 266–275

Contents lists available at [ScienceDirect](http://ScienceDirect)  
ELSEVIER  
Sensors and Actuators A: Physical  
journal homepage: [www.elsevier.com/locate/sna](http://www.elsevier.com/locate/sna)

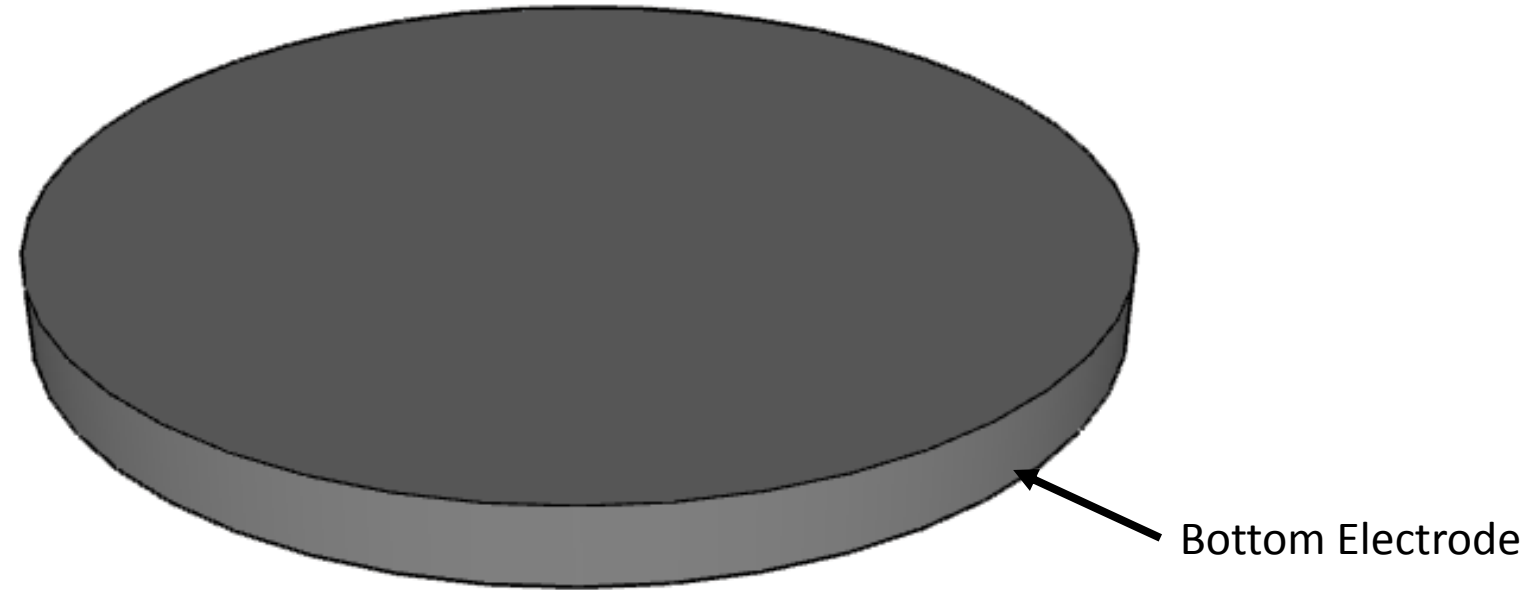
**Piezoelectric MEMS resonator-based oscillator for density and viscosity sensing**  
Tomás Manzanque<sup>a,\*</sup>, Víctor Ruiz-Díez<sup>a</sup>, Jorge Hernando-García<sup>a</sup>, Elisabeth Wistrela<sup>b</sup>,  
Martin Kucera<sup>b,c</sup>, Ulrich Schmid<sup>b</sup>, José Luis Sánchez-Rojas<sup>a</sup>

**...viscosity sensing in a low-flow environment**  
...es Jundt<sup>a</sup>,  
...mercier<sup>c</sup>

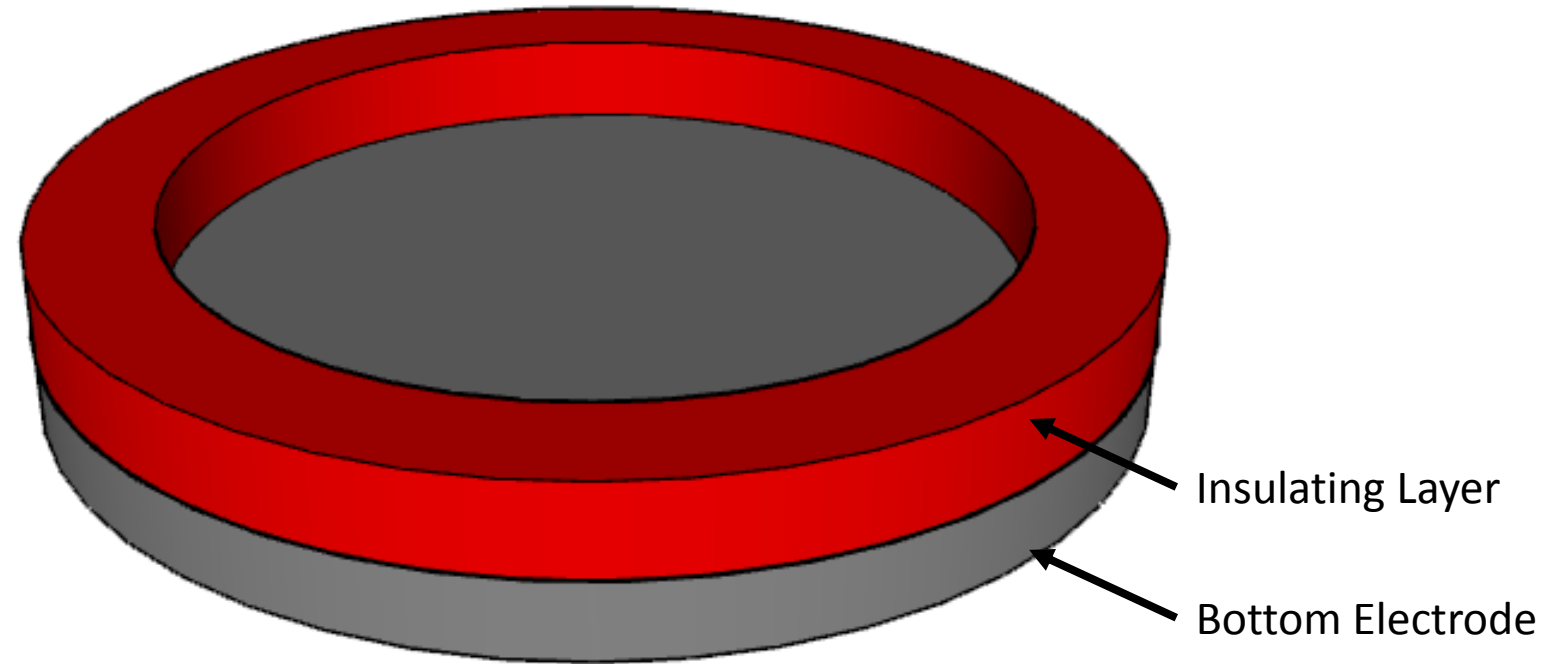
SENSORS ACTUATORS A PHYSICAL  
[www.elsevier.com/locate/sna](http://www.elsevier.com/locate/sna)

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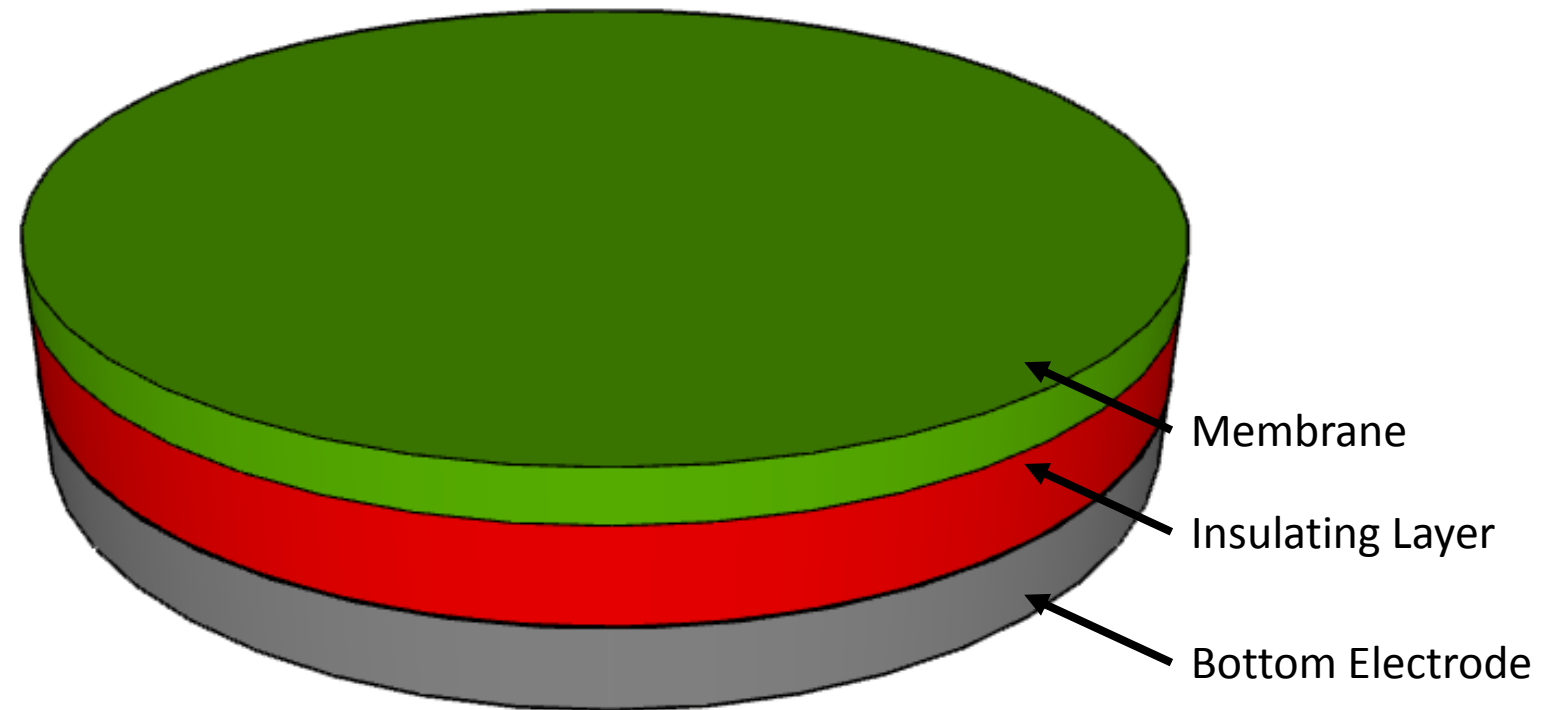
# CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCER (CMUT)



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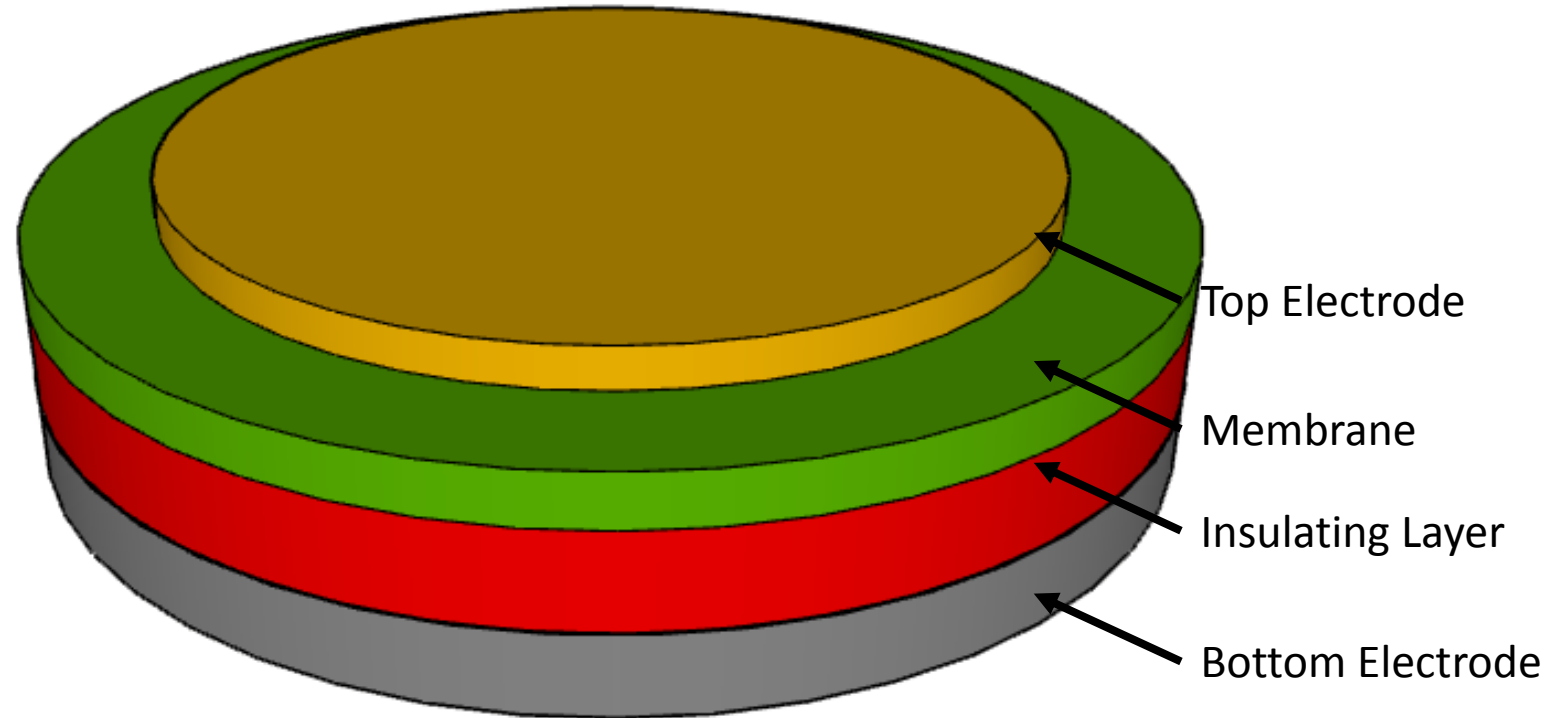


# CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCER (CMUT)





# CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCER (CMUT)





# CMUT VISCOMETER



- Transmitter CMUT

# CMUT VISCOMETER

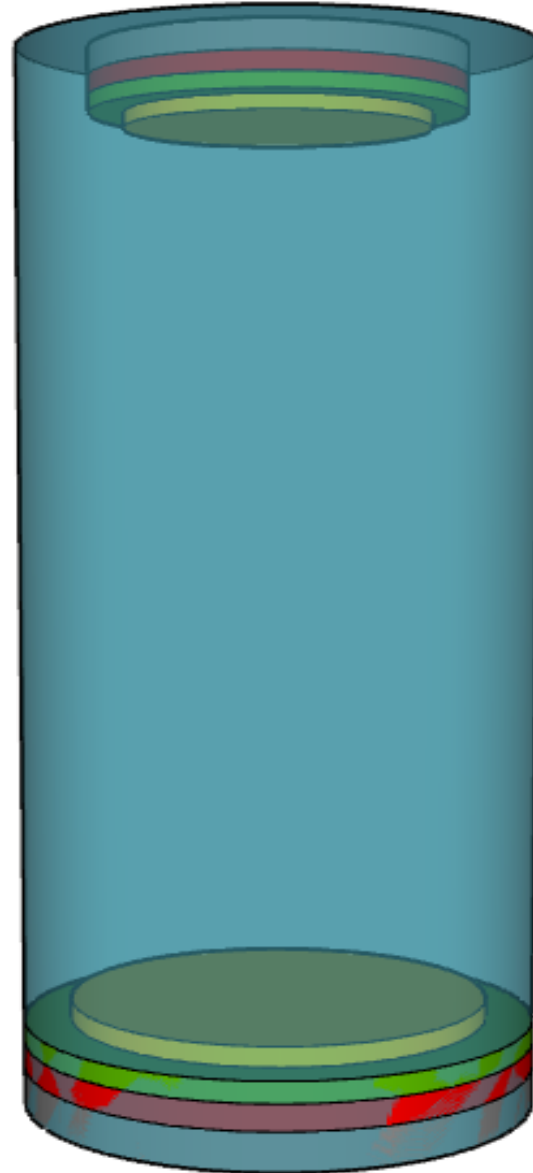


- Transmitter CMUT
- Receiver CMUT



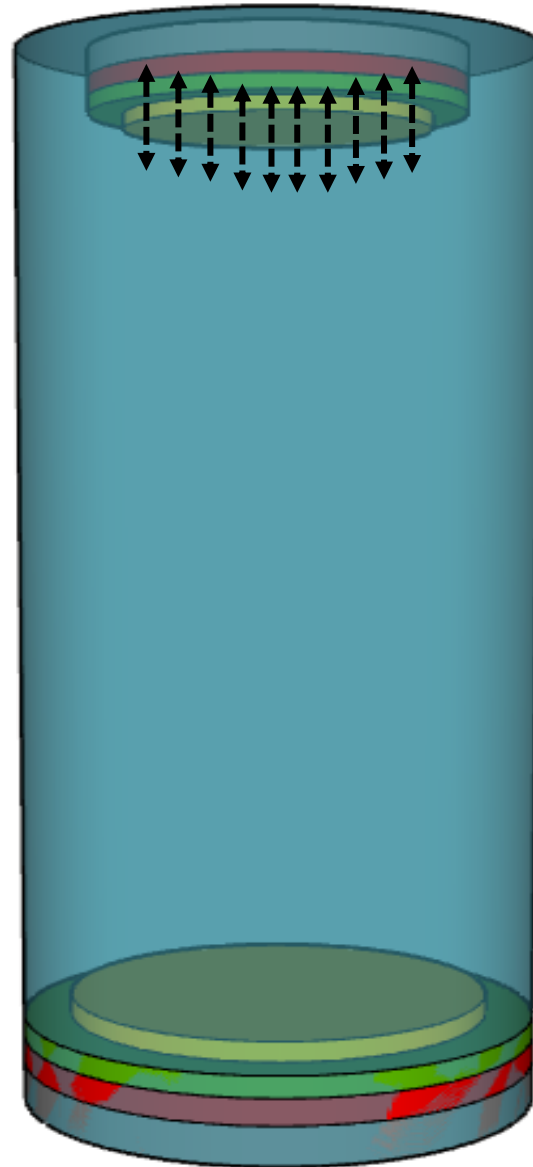
# CMUT VISCOMETER

- Transmitter CMUT
- Receiver CMUT
- Fluid Under Inspection



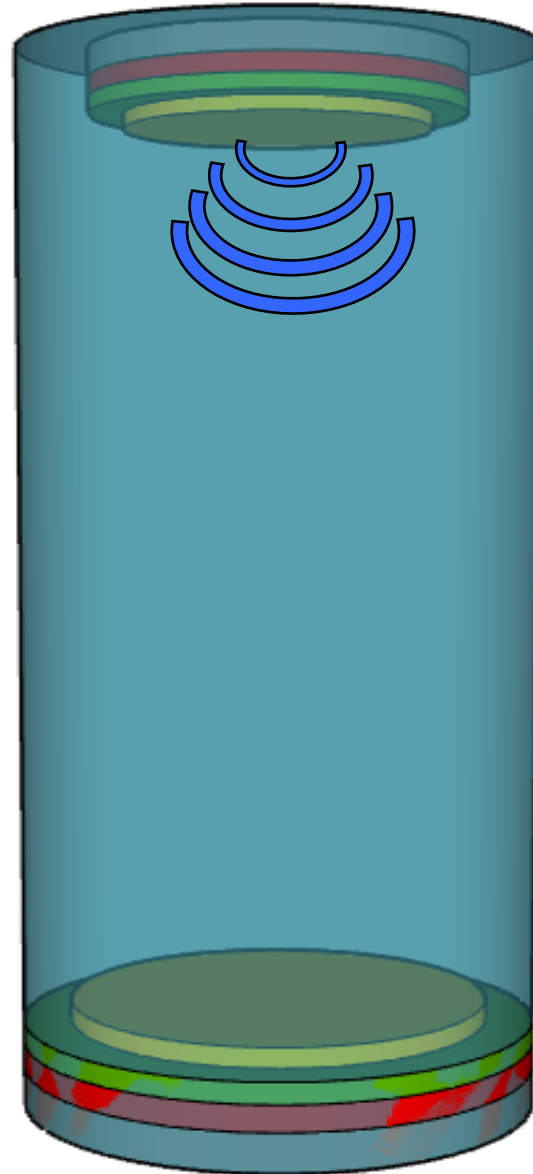
# WORKING

- Actuation of CMUT



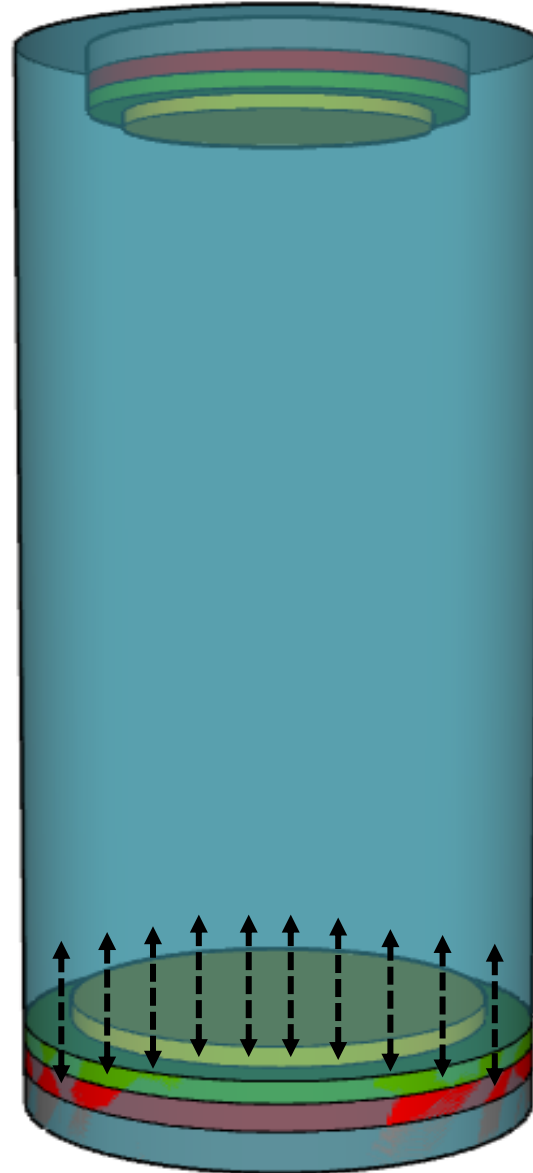
# WORKING

- Actuation of CMUT
- Transfer of Pressure wave in liquid column



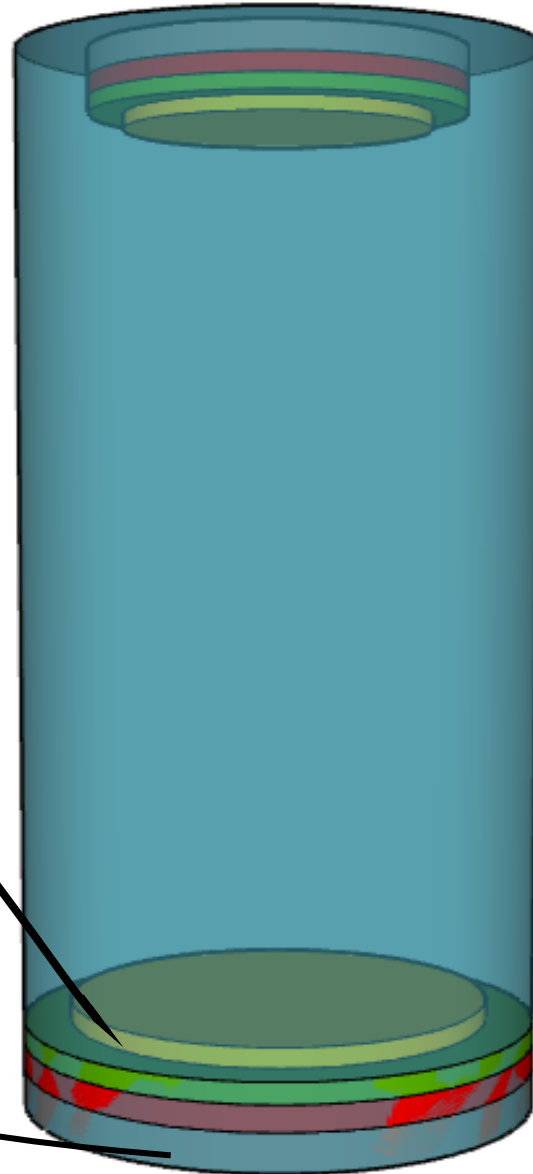
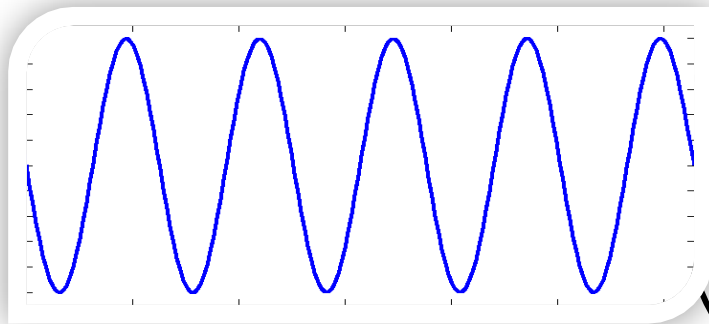
# WORKING

- Actuation of CMUT
- Transfer of Pressure wave in liquid column
- Vibration of Receiver CMUT



# WORKING

- Actuation of CMUT
- Transfer of Pressure wave in liquid column
- Vibration of Receiver CMUT
- Sensing of Signal using Electronics







# USE OF COMSOL MULTIPHYSICS



1. CMUT Parameters
2. Actuation of Transmitter CMUT
3. Pressure Induced in the Liquid Column
4. Vibration of the Receiver CMUT
5. Sensing of Signal



# USE OF COMSOL MULTIPHYSICS



## 1. CMUT Parameters

2. Actuation of Transmitter CMUT

3. Pressure Induced in the Liquid Column

4. Vibration of the Receiver CMUT

5. Sensing of Signal



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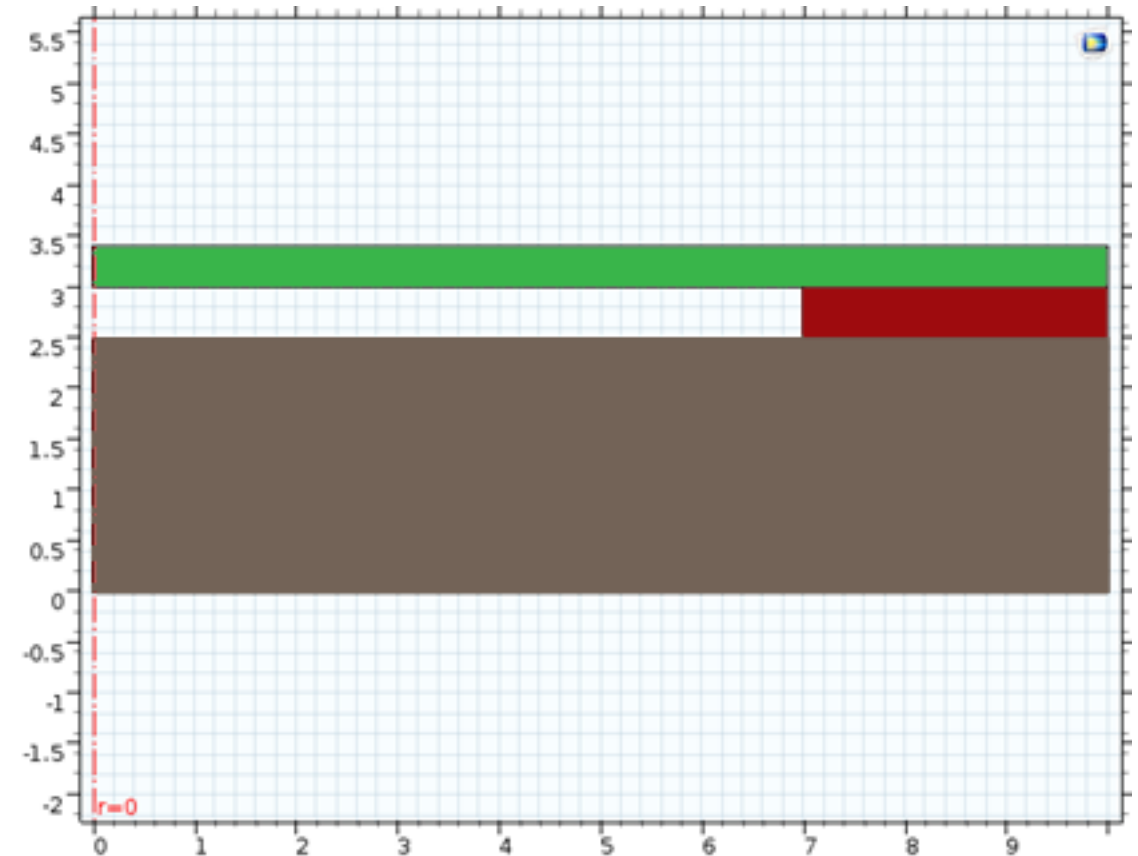
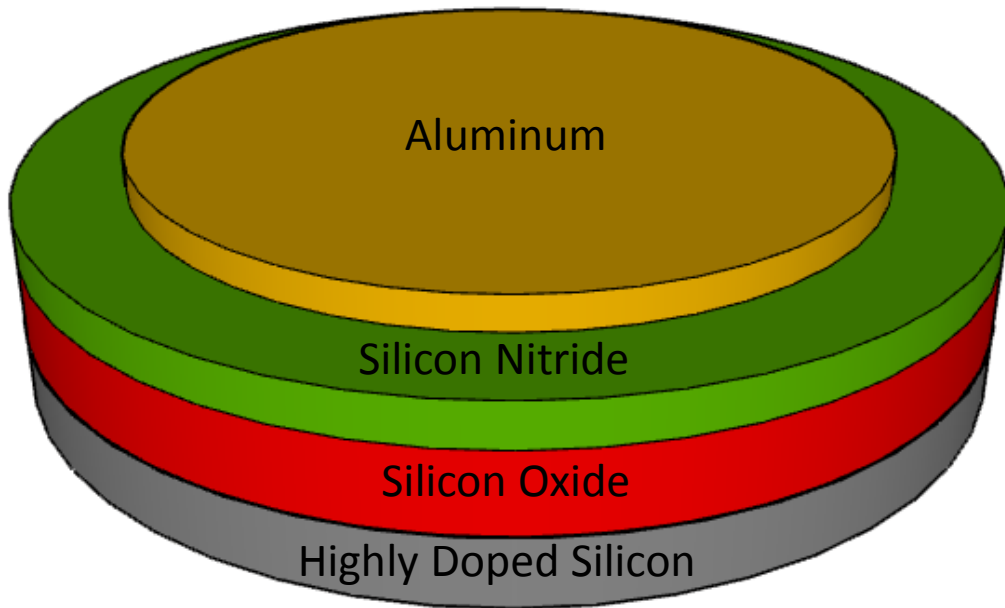
# USE OF COMSOL MULTIPHYSICS



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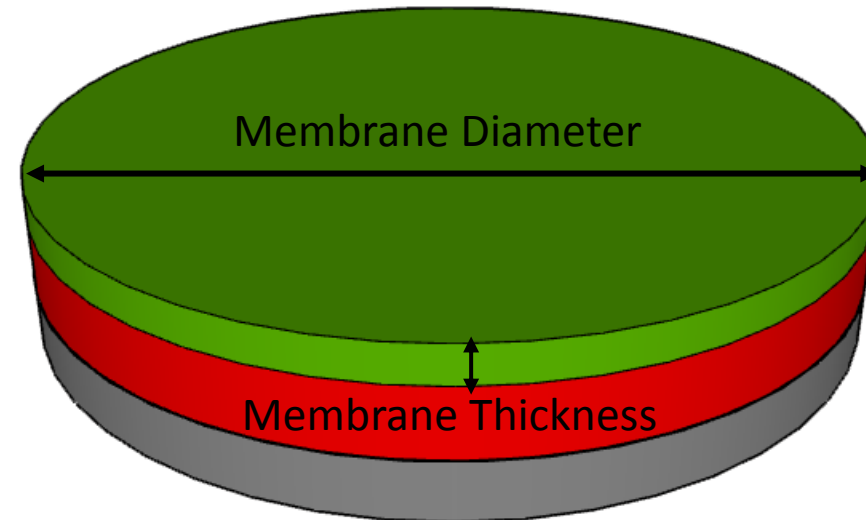
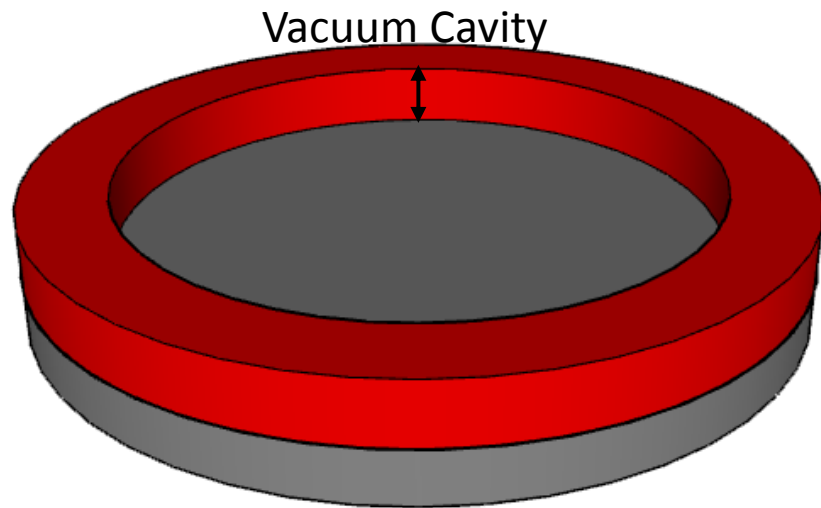
# CMUT PARAMETERS - MATERIALS USED

\*PHYSICS USED: SOLID MECHANICS



# CMUT PARAMETERS - PARAMETRIC SWEEP

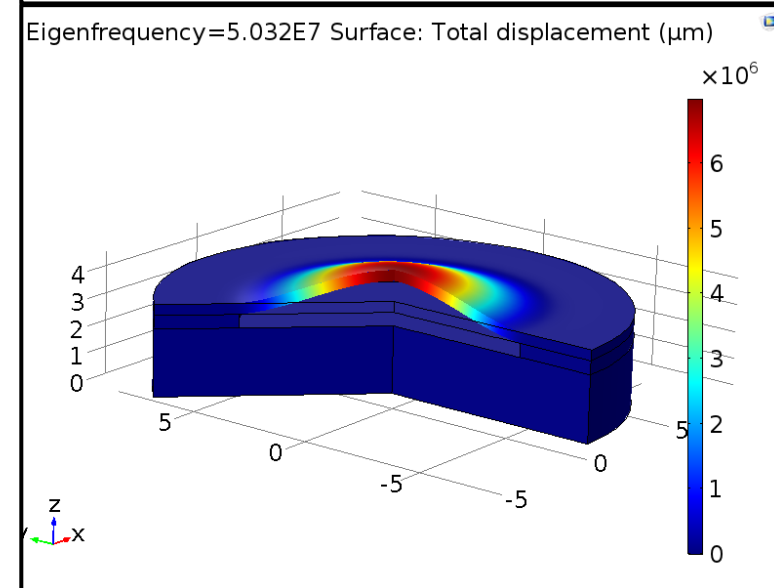
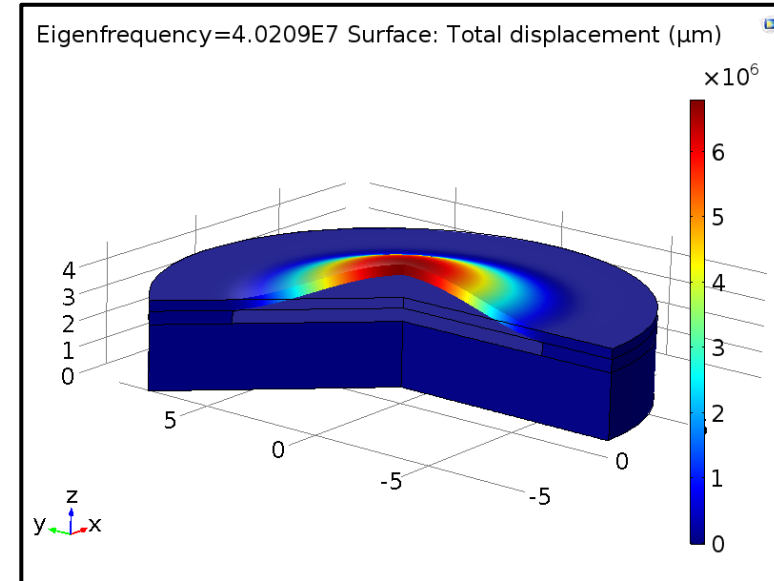
\*PHYSICS USED: SOLID MECHANICS





# CMUT PARAMETERS - COMPUTED

Parameters	Transmitter	Receiver
Resonance Frequency	40 MHz – 50 MHz	40 MHz – 50 MHz
Membrane Thickness	100 nm	400 nm
Membrane Diameter	5.85 $\mu\text{m}$ – 6.35 $\mu\text{m}$	11.65 $\mu\text{m}$ - 13 $\mu\text{m}$
Vacuum Cavity	0.1 $\mu\text{m}$	0.5 $\mu\text{m}$
Pull-in voltage	67 v	> 67
DC voltage	30V	10V
AC voltage	5V $V_{pp}$	-



# ACTUATION of Tx-CMUT

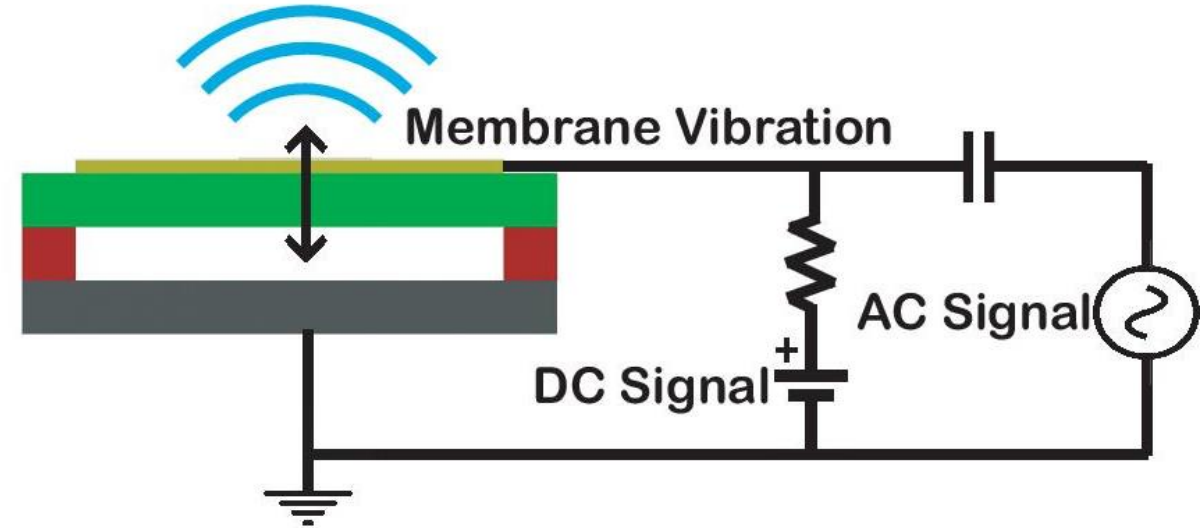
## VOLTAGE APPLIED

$$V_{DC} = 30 \text{ V}$$

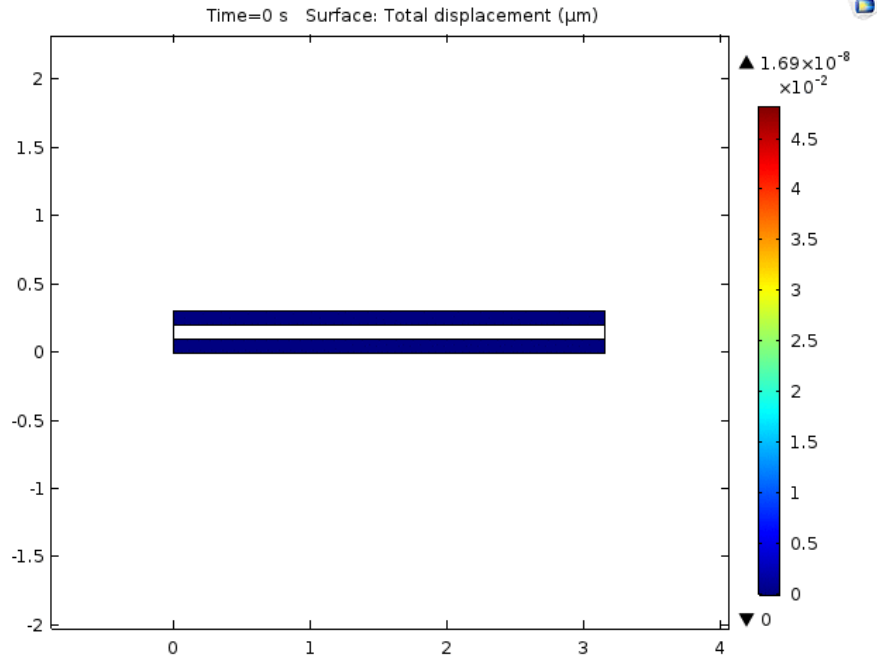
$$V_{AC} = 5 \text{ V}_{PP}$$

FREQUENCY OF AC SIGNAL: 21.16  
MHZ

Emitted Ultrasonic Waves



# ACTUATION OF Tx-CMUT

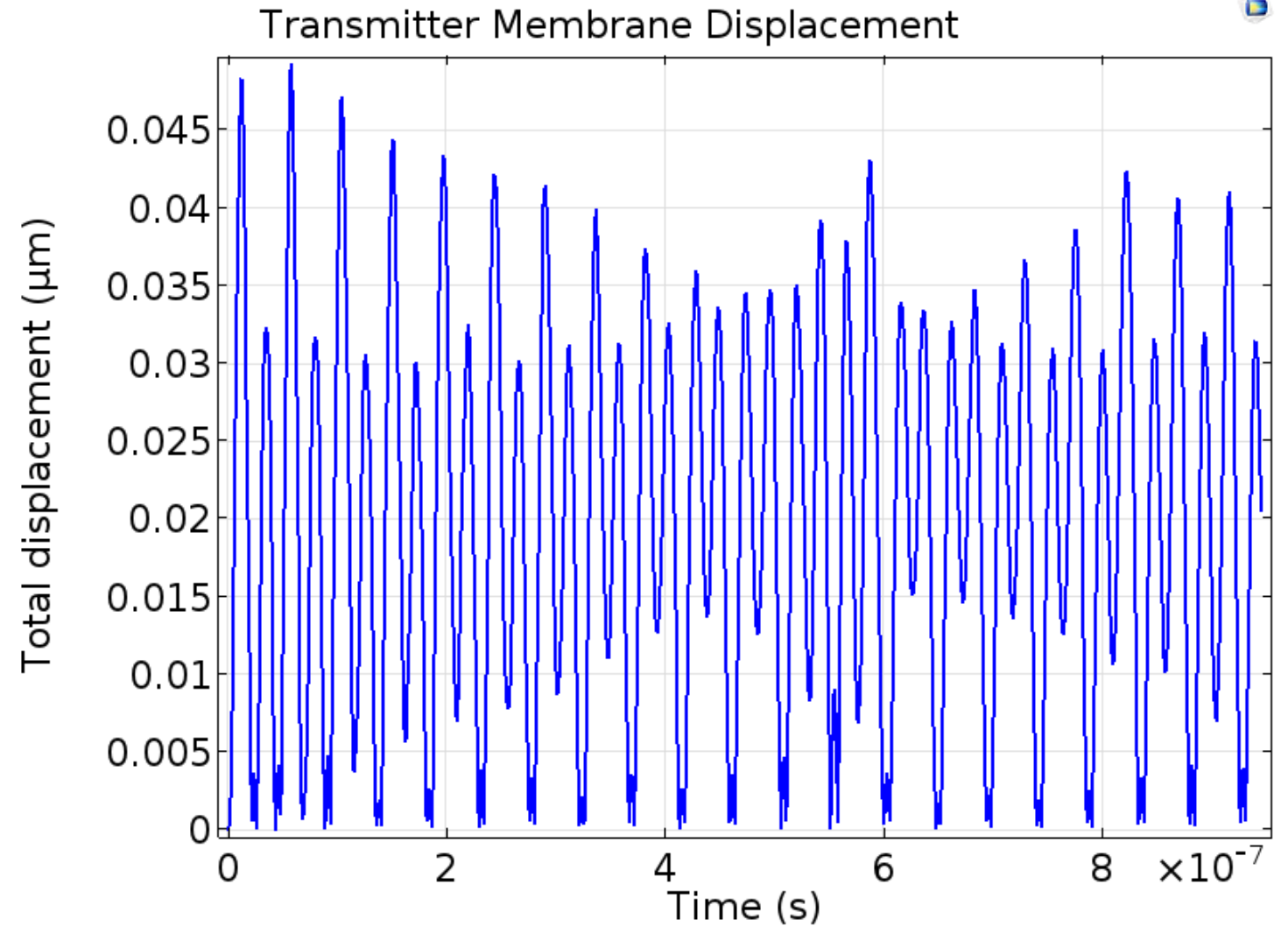


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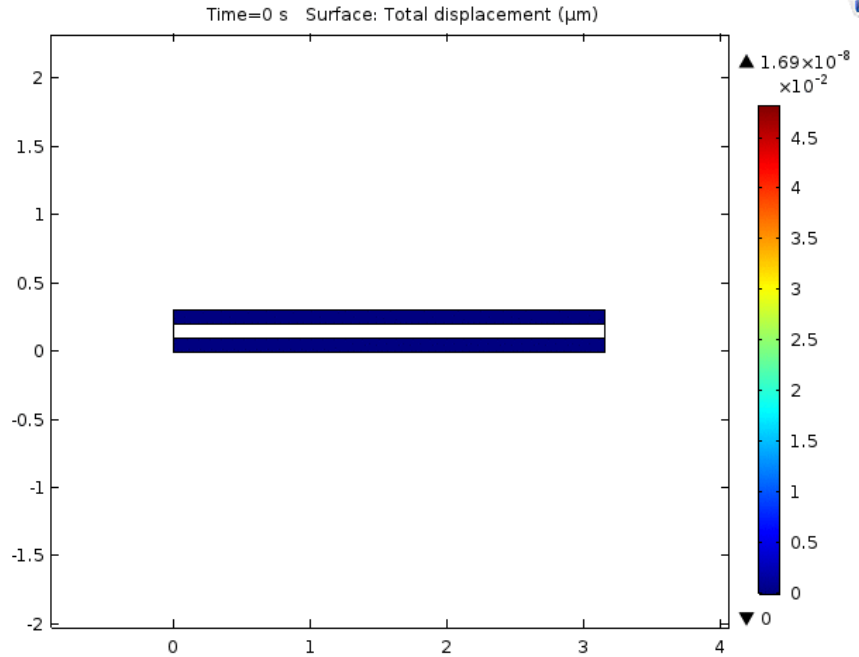
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\*PHYSICS USED: ELECTROMECHANICS

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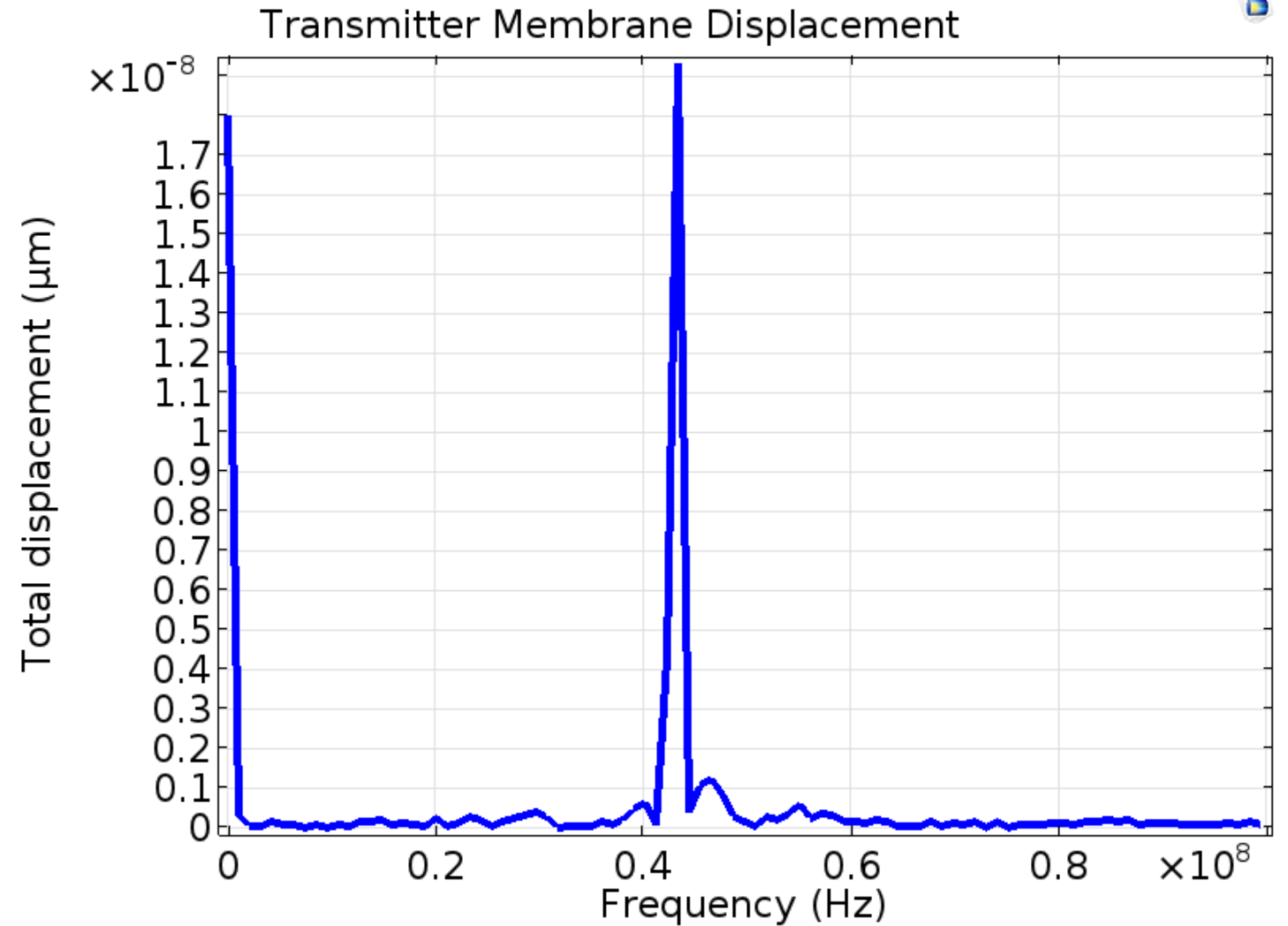


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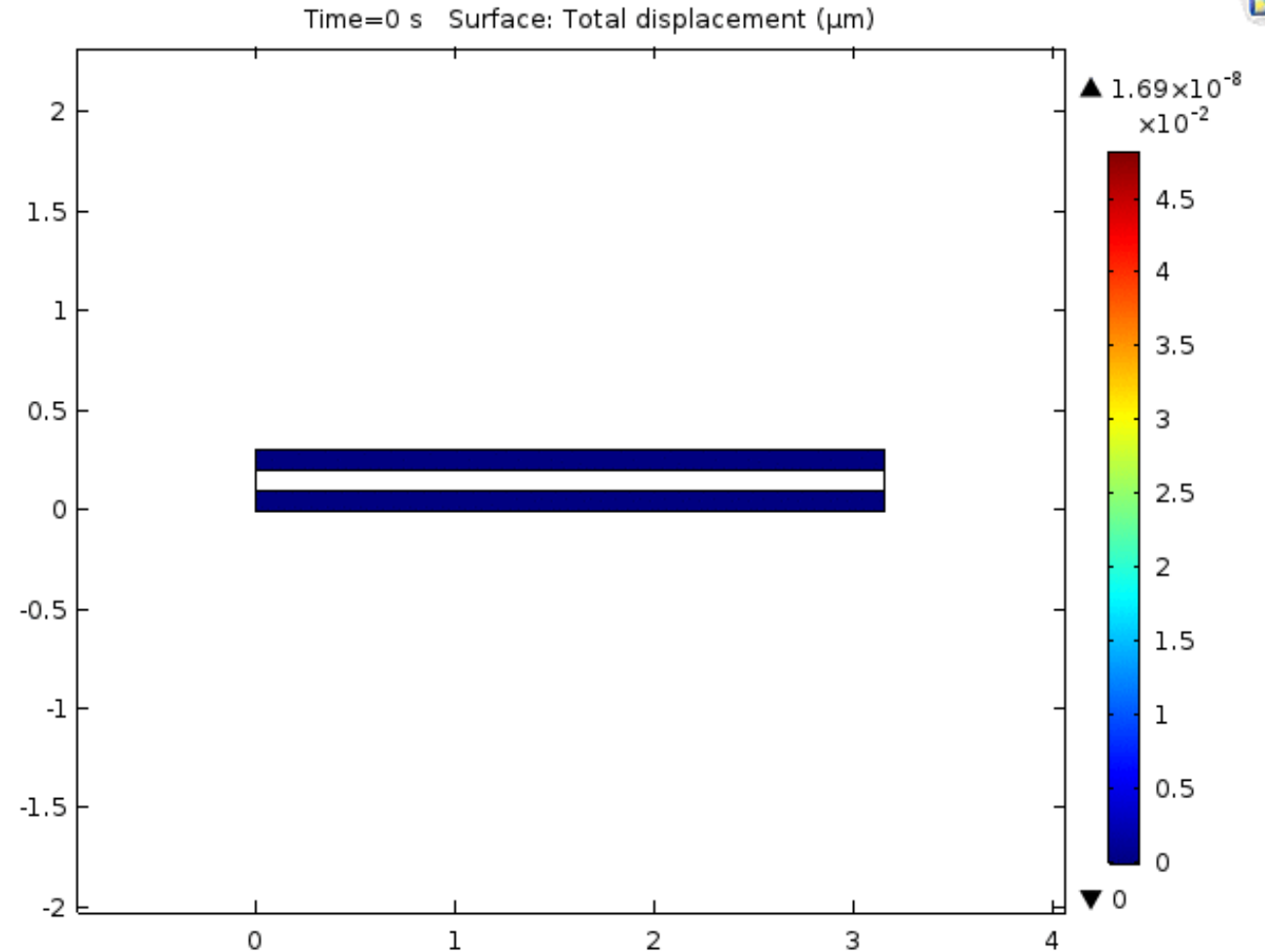


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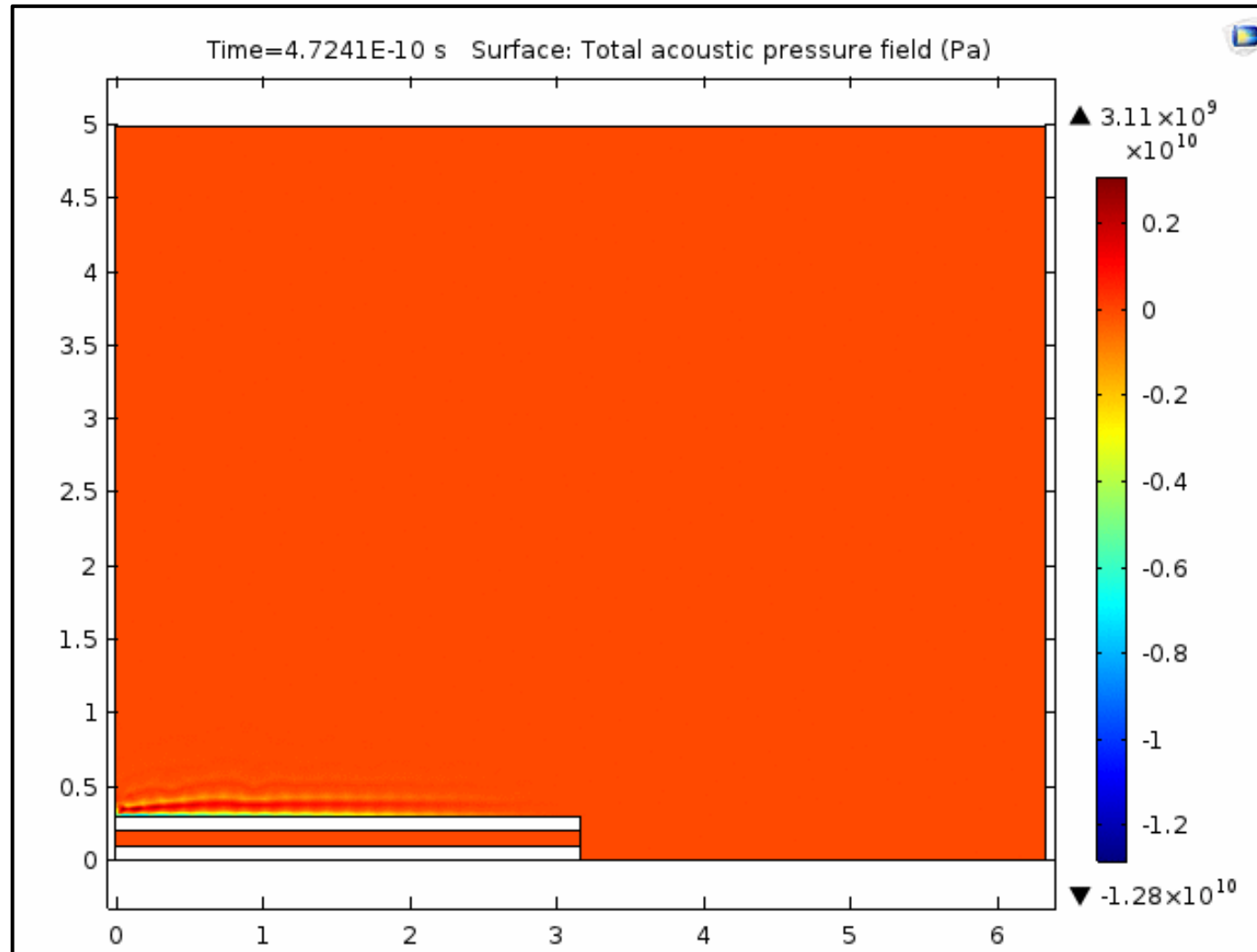
# PRESSURE GENERATED BY CMUT

PHYSICS USED: ACOUSTIC STRUCTURE INTERACTION

USED PRESCRIBED DISPLACEMENT AS A FUNCTION OF RADIAL DISTANCE



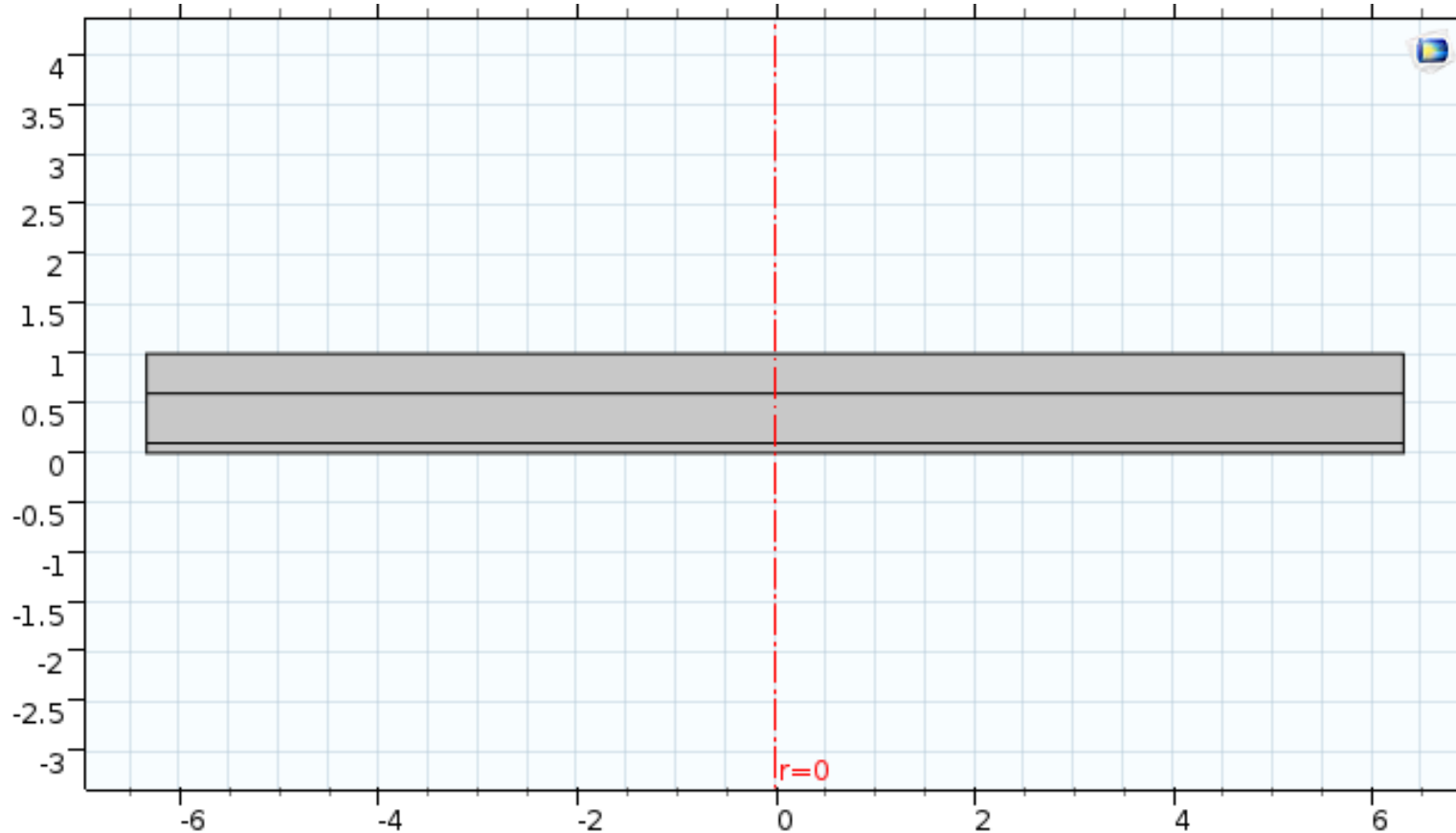
# GENERATION OF PRESSURE BY CMUT



Peak Pressure = 10 MPa

\*PHYSICS USED: : ACOUSTIC STRUCTURE INTERACTION

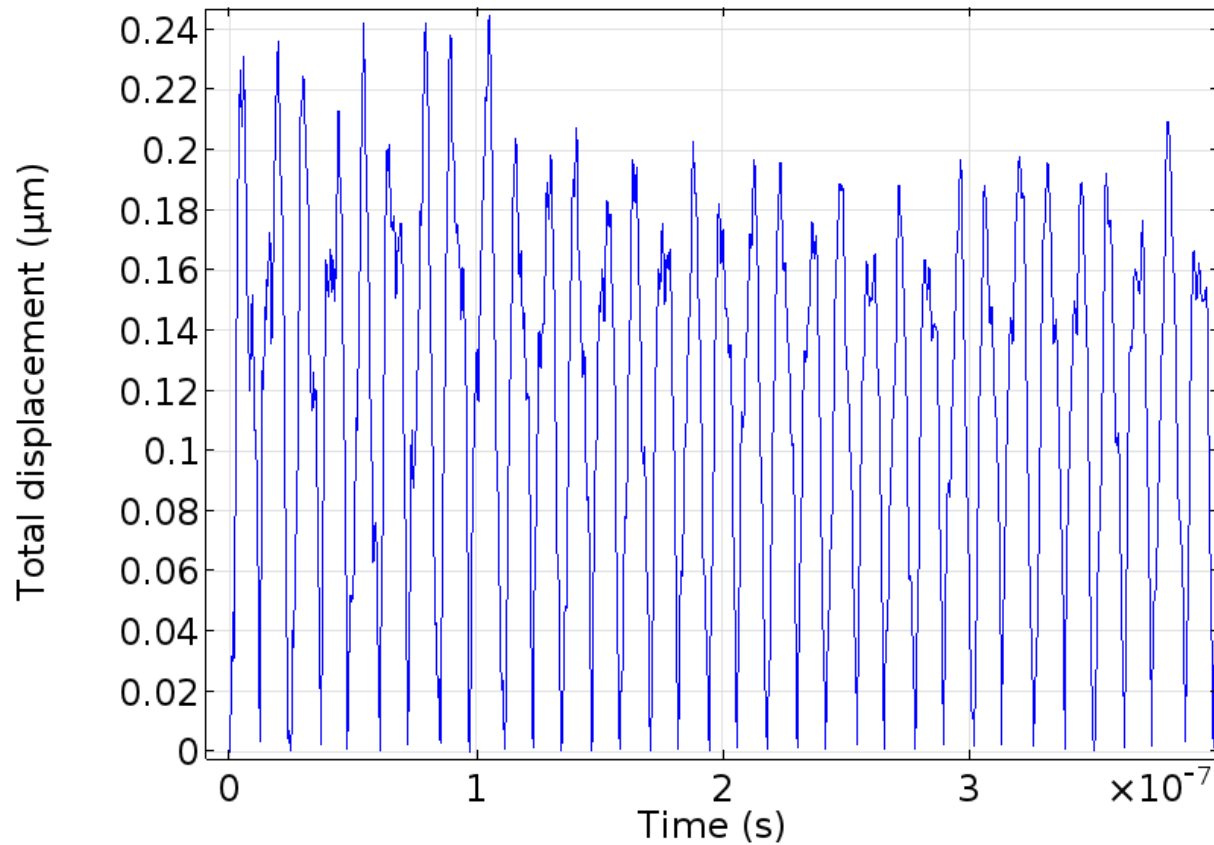
# VIBRATION OF RECEIVER MEMBRANE WHEN IMPULSE BOUNDARY LOAD IS APPLIED



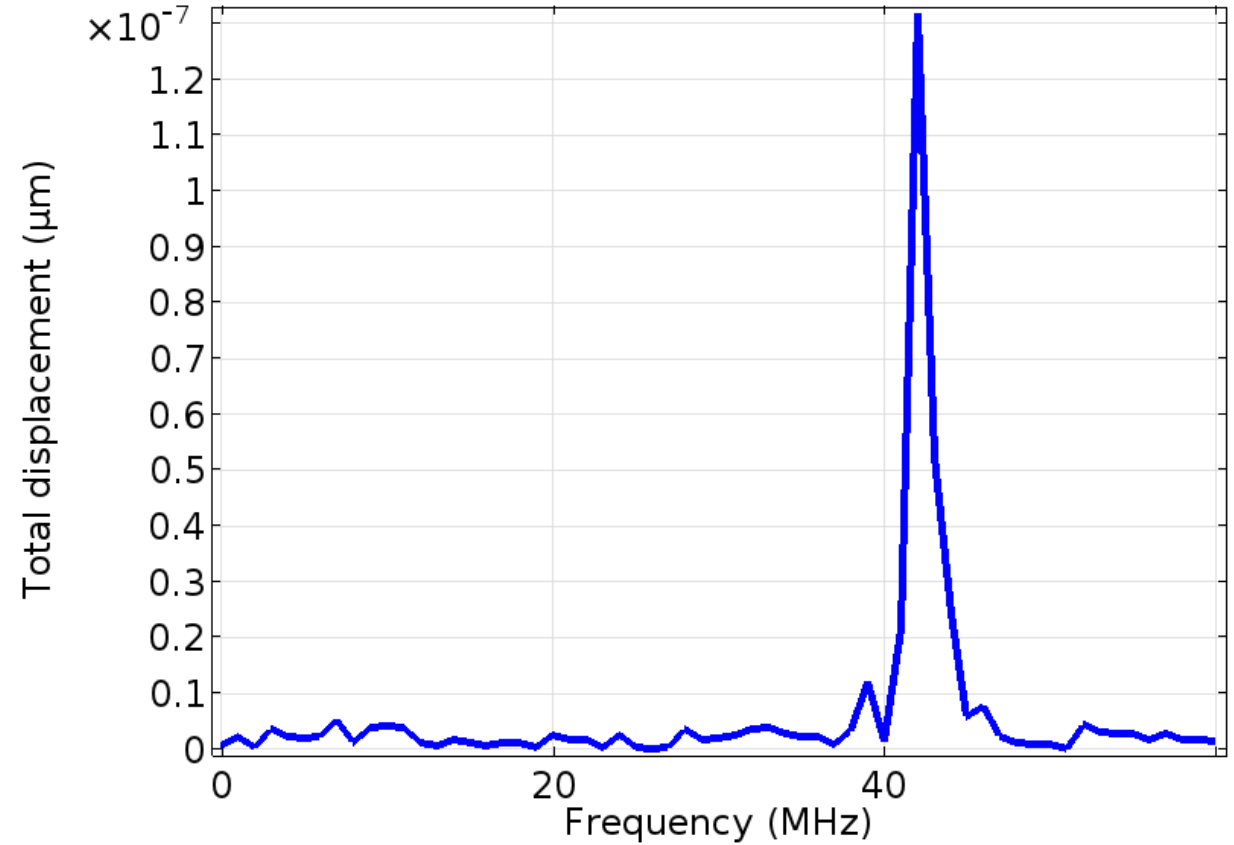
\*PHYSICS USED: SOLIDMECHANICS

# VIBRATION OF RECEIVER MEMBRANE WHEN IMPULSE BOUNDARY LOAD IS APPLIED

Receiver Membrane Displacement as a Function of Time



Frequency Response of Receiver Membrane Displacement

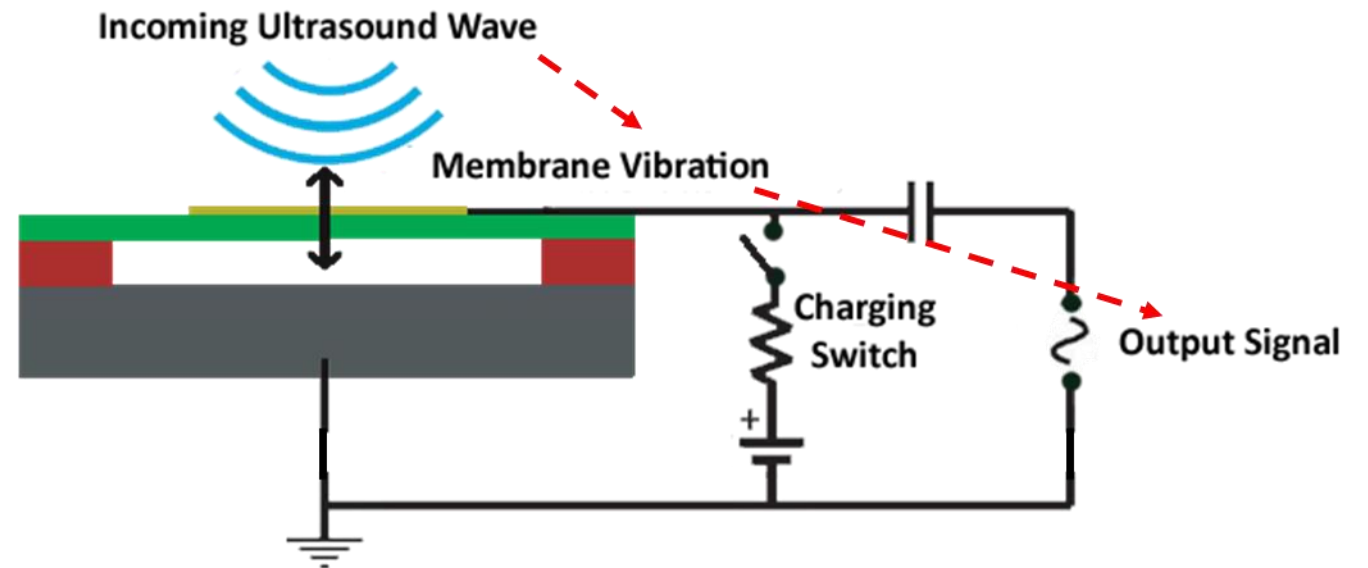


**\*PHYSICS USED: SOLIDMECHANICS**

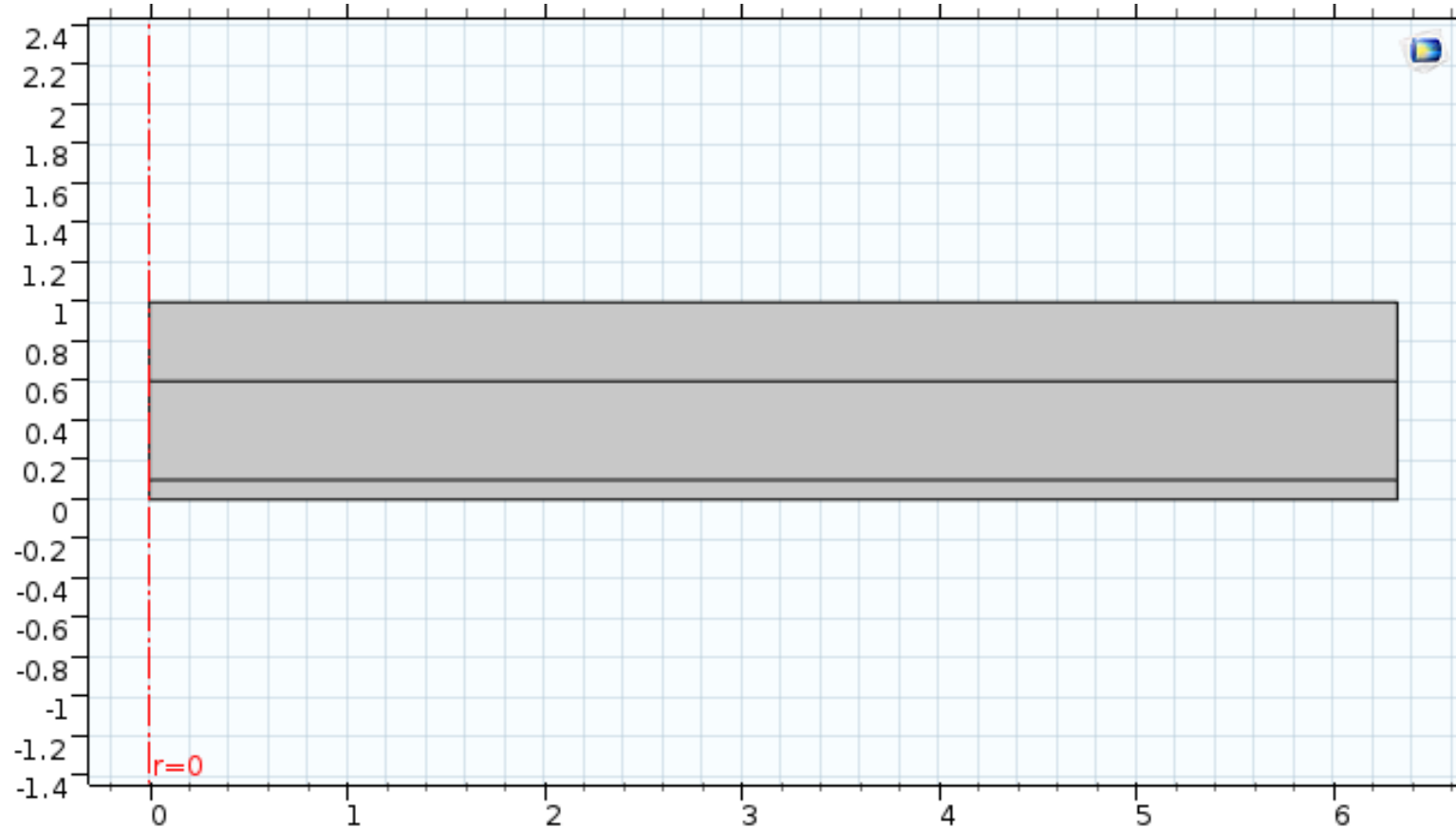


# OUTPUT SIGNAL SENSING

VOLTAGE APPLIED	10 V
C AT STEADY POSITION	2.23 fF
CHARGE	22.3 fC



# OUTPUT SIGNAL SENSING

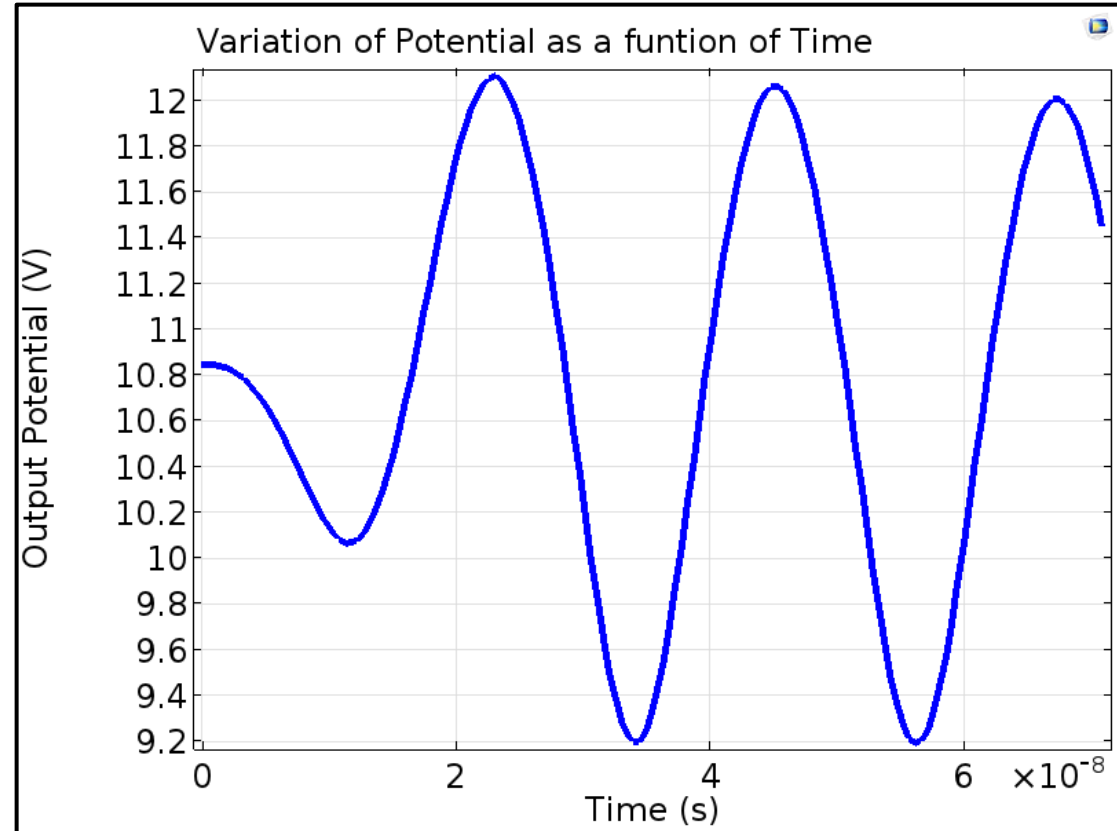
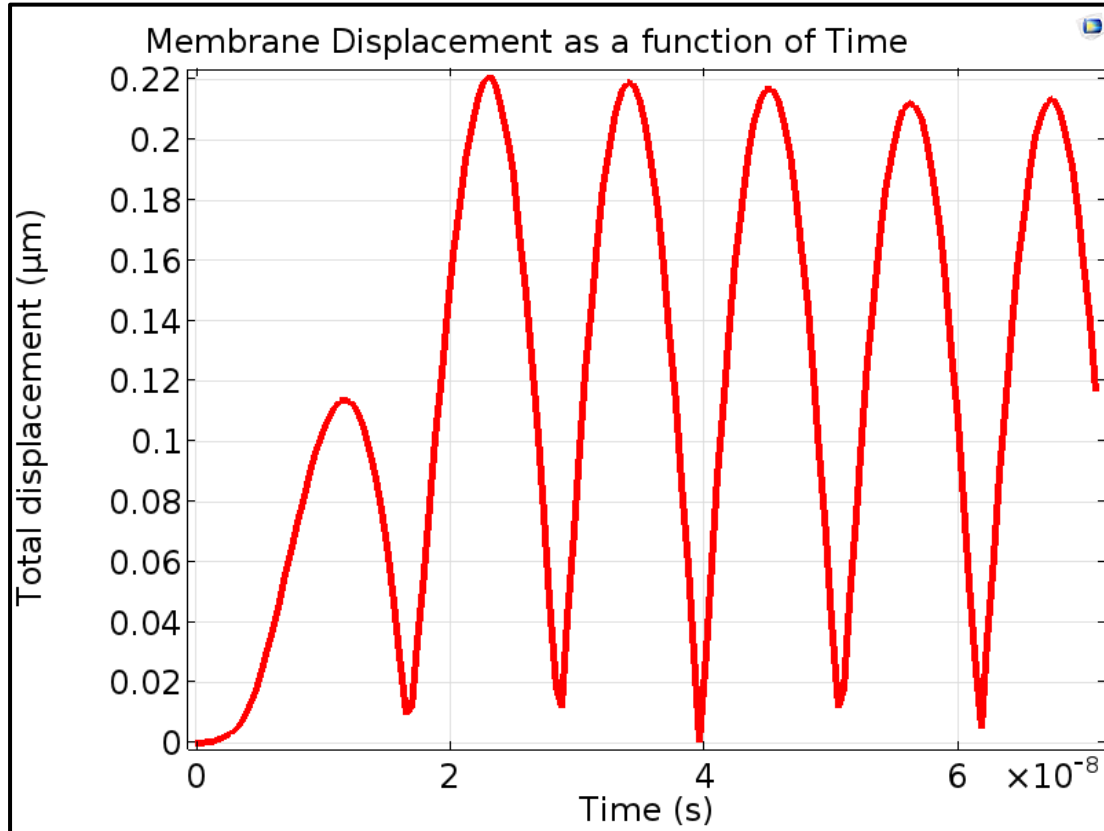


$$\text{Boundary Load} = 10^6 \cdot \sin(\pi Ft) * (t < 1/F)$$

\*PHYSICS USED:  
ELECTROMECHANICS

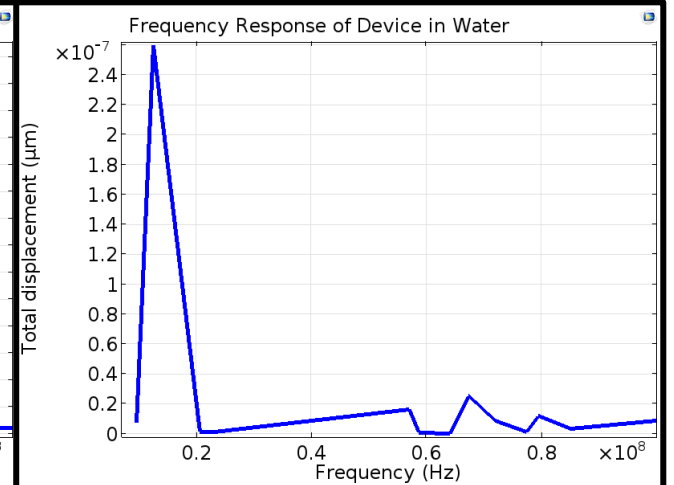
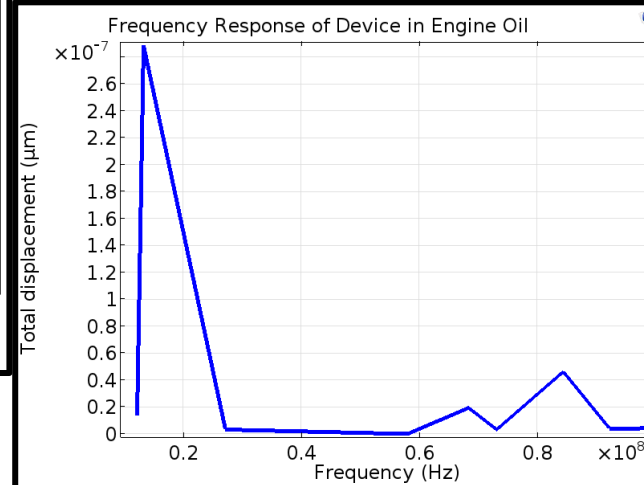
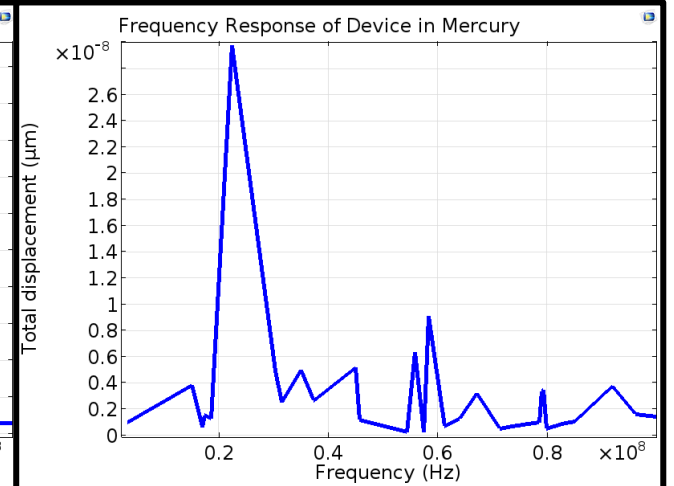
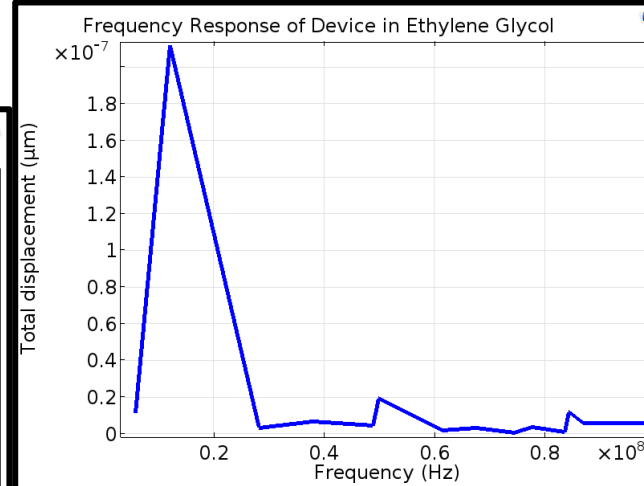
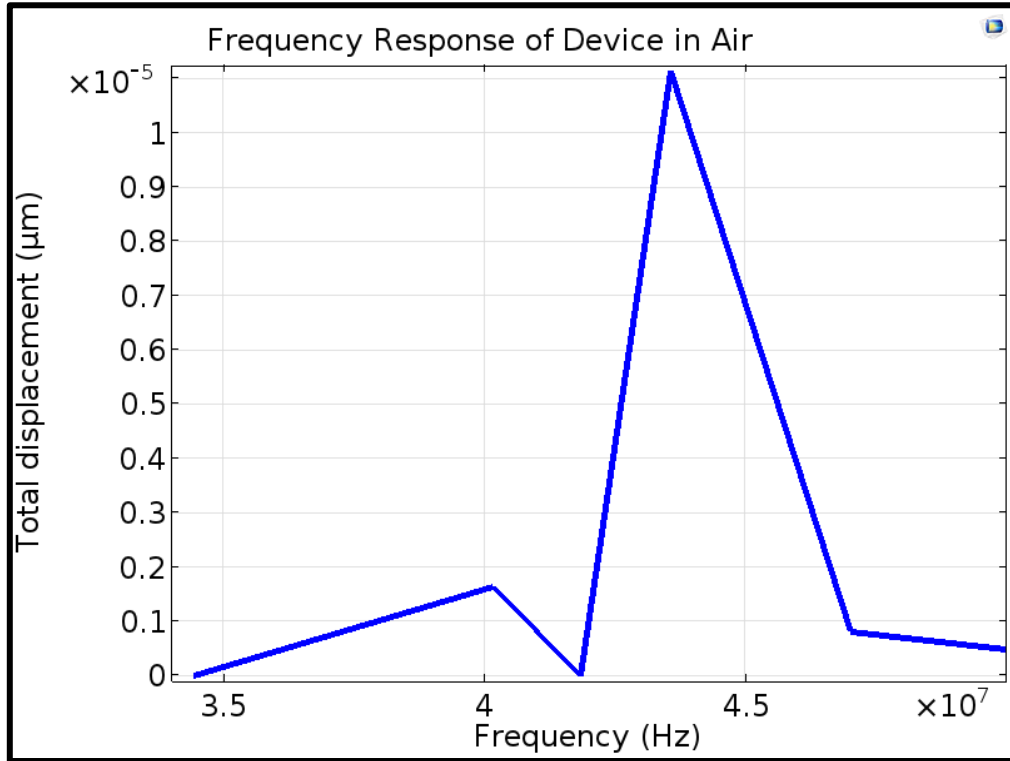
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# SENSING FROM Rx-CMUT



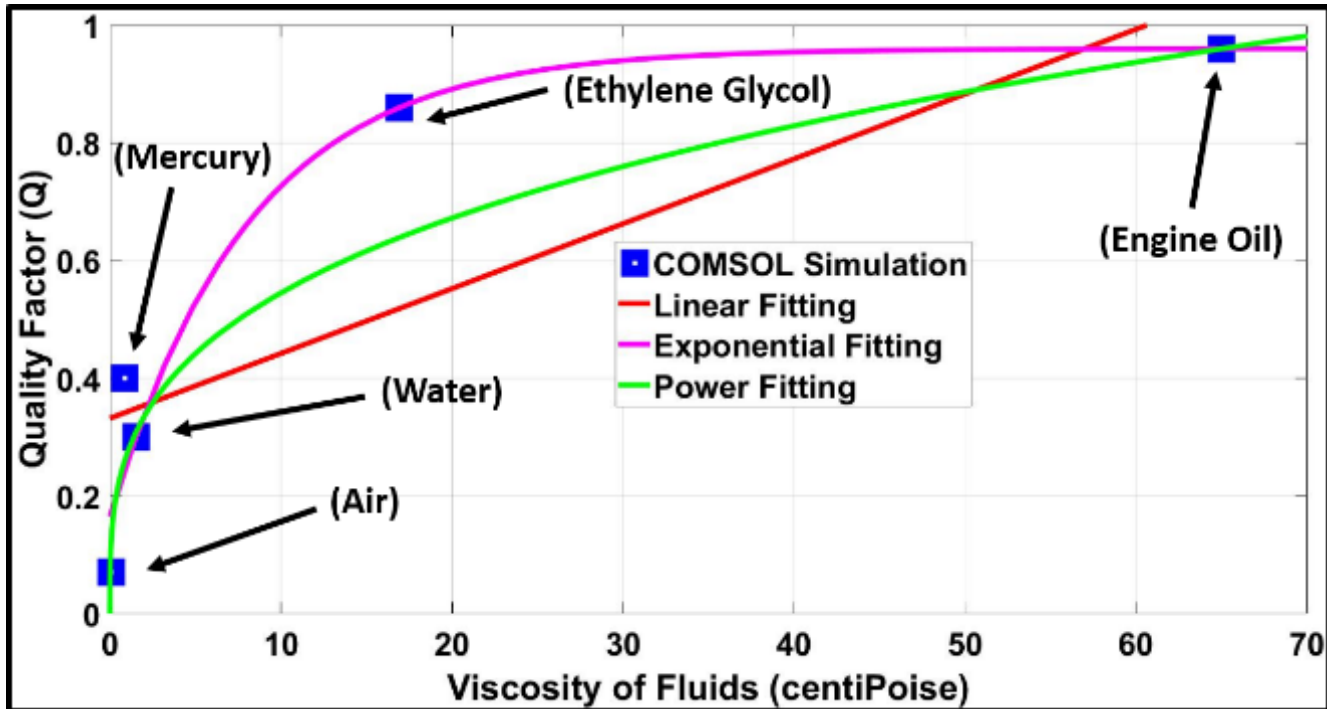
**\*PHYSICS USED: ELECTROMECHANICS**

# FREQUENCY RESPONSE OF THE RECEIVER CMUT IN DIFFERENT FLUIDS



\*PHYSICS USED: SOLIDMECHANICS

# FITTING RESULTS



- Quality factor varies exponentially with the viscosity of fluids which provides efficient sensitivity below the viscosity of 50 cp.
- The method of viscosity sensing can further be improved by improving post processing of the electronic signal.

$$\text{Quality Factor} = \frac{\text{Bandwidth}}{\text{Resonant Frequency}}$$

**THANK YOU**