

**Frequency Response of MEMS Microphone Diaphragms**  
**MEMS II Project Update (November 16<sup>th</sup>, 2004)**  
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**Project Definition:**

Numerous MEMS-scale microphones have been designed and some have already been manufactured. There is currently a wide range of applications including hearing aids, cell phones, and conventional microphones. With the ability to increase frequency response and sensitivity, while decreasing cost (\$1 - \$7) and size, MEMS condenser microphones are the future of sound measurement. They are expected to become over 20% of the 1.6 billion sound sensing units sold by 2006.

Therefore, this project is an investigation of one particular microphone design that is proposed specifically for hearing aids, although the authors claim it can be used for numerous other applications with the appropriate IC. This study includes modeling the microphone in Coventorware, inputting perfect C-notes from the lower, middle and upper octaves, and investigating the frequency output for these cases. Based on these results, the flexures will then be redesigned and/or relocated in order to maximize the performance of this microphone. This will result in a new design that will meet the stringent size constraints for the hearing aid application, while providing the highest frequency response range.

**Design and Layout:**

The design being modeled and studied was originally formulated by Sazzadur Chowdhury and has been slightly adapted to be easier to model and study [1]. The original design has a socket that allows it to be “plugged” in to a CMOS environment, but this is not necessary for this project. Also, the flexures originally connect to the substrate layer, but the boundary conditions were set in order to properly account for this. This shortens the computational time and simplifies the layout and mesh. Originally, it was believed that only ¼ of the diaphragm must be modeled, but instead the entire setup was modeled in case future modifications are not symmetric. Therefore, the resulting design parameters are shown in Table 1.

Diaphragm Area	1 mm x 1 mm
Diaphragm Thickness	0.8 μm
Diaphragm Material	Polysilicon Germanium
Air Gap Thickness	2 μm
Back Plate Thickness	1 μm
Bias Voltage	12 Volts
Flexure Width	10 μm
Flexure Length	200 μm

Table 1: Design parameters [1]

The design parameters provided in Table 1 are all identical to the original design proposed by Sazzadur Chowdhury. Only one assumption must be made in order to complete the design. The vent-hole density of the bottom conductor must be arbitrarily chosen because it was not provided in the original layout. This should not affect the behavior of the microphone in Coventorware except that the bottom conductor surface area is reduced when increasing the ventilation-hole density. The vent-hole density was chosen for this study to be 33 % of the total area of the bottom conductor based on other designs [2]. This results in a design shown below in Figure 1. The left photo is an oblique view where the yellow layer is the upper conductor with eight thin flexures around the perimeter. The right photo is a bottom view showing the blue lower conductor with the vent-holes.

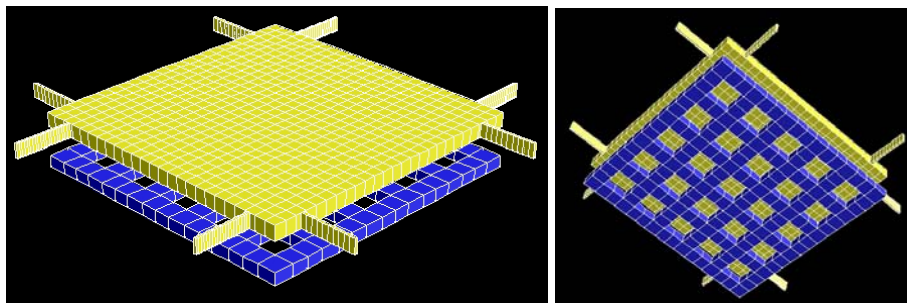


Figure 1: Bottom and top views of the microphone design modeled in Coventorware

**Analysis and Results:**

Thus far, preliminary analyses have been performed in order to determine how much pull-down occurs with only the 12-volt bias voltage is applied to the upper diaphragm. This was investigated using Co-Solve and the results are shown in Figure 2.

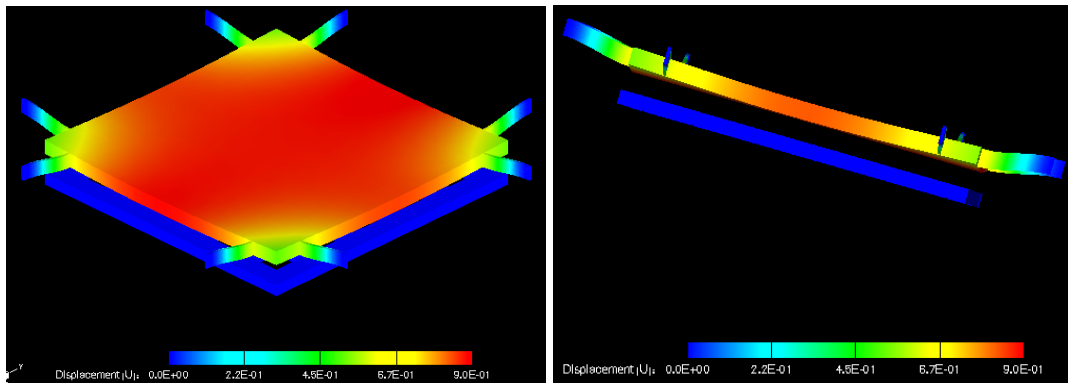


Figure 2: Oblique and side views of the diaphragm displacement with the 12-volt bias voltage applied

The 12-volt bias voltage results in a pull-down of approximately 0.9  $\mu\text{m}$ , providing a new equilibrium air gap distance of 1.1  $\mu\text{m}$ . Based on research, it was determined that a pure C-note is a perfect sinusoidal wave and the frequencies of lower, middle, and upper C-notes are 132 Hz, 264 Hz, and 528 Hz respectively [3]. Therefore these frequencies are being input with different amplitudes to represent sound pressure levels of a whisper (30 dB), normal conversation (70 dB), and shouting (90 dB) [4]. This is possible using the MEMMech solver to provide a transient response from a periodic input. This has been attempted but no results are yet available.

**Schedule and Milestones:**

Thus far, many milestones have been reached. The design has been built and proper boundary conditions have been applied. It was determined that a transient response was available and a periodic pressure force could be applied in order to model a pure sound wave. Also, a conversion from sound intensity (decibels) to pressure (Pa) was recently found [5]. This allows the sound wave to be properly input into Coventorware, but there are still many more analyses to be performed. The schedule is shown below in Table 2.

Week of:	17-Oct	24-Oct	31-Oct	7-Nov	14-Nov	28-Nov	5-Dec	12-Dec
Project Proposal	Completed							
Project Definition	Start				Completed			
Initial Oral Presentation					Start	Due		
Final Oral Presentation					Start		Due 11-Dec	
Final Report				Start				Due 16-Dec
Initial Model Built	Start		Completed					
Initial Simulations Run			Start		Finish goal			
Modified Setups Simulated					Start	Finish goal		
Analytical Work if Necessary	Start					Finish goal		

**Sources:**

[1] Chowdhury, Sazzadur, Ahmadi, M., et. al. “A Surface Mountable MEMS Beamforming Microphone Array and Associated MEMS Socket Structure.” Symposium on Microelectronics Research and Development in Canada. University of Windsor Research Centre for Integrated Microsystems. June 7, 2001.

[2] J. Bernstein. “MEMS Microphones at Draper.” Microsystems Technology Office at Darpa. Aug. 1999.

[3] Abdullah, T. Yahaya. “Music Scales – Frequency, Notes, Octaves, Tuning, Scales, Modes, Pentatonics, Transforms.” <http://tyala.freeyellow.com/4scales.htm>.

[4] Geoff Husband. “What’s In Your Music – The Hz’s and the dB’s of Real Music!” TNT-Music. [http://www.tnt-audio.com/topics/frequency\\_e.html](http://www.tnt-audio.com/topics/frequency_e.html).

[5] The Engineering Toolbox. “Sound Power, Intensity, and Pressure.” [http://www.engineeringtoolbox.com/27\\_57.html](http://www.engineeringtoolbox.com/27_57.html).