MEMS Microphone Design and Signal Conditioning

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OUTLINE

Introduction
Basic Capacitive Microphone
Pressures
Diaphragm Calculations
Microphone Design
Microphone Fabrication
Signal Conditioning
Microphone Evaluation
Results
This document presents theoretical and experimental results for capacitive microphone design, fabrication and evaluation. The microphone was fabricated using a PCB for the rigid backing capacitor plate of the microphone. Aluminum foil was used for the flexible sensing capacitor plate of the microphone. Simple signal conditioning electronics converts the change in capacitance to a change in voltage. The analog output was obtained for various frequency audio tones generated using speakers connected to a personal computer.
COMMERCIAL MICROPHONES

Akustica
Analog Devices
Boesch
Emkay Sisonic
Futurlec
Infineon
Knowles
Motorola
STMicroelectronics
TI
Others
**Akustica AKU230**
It uses a free-floating diaphragm, and a capacitive sensing based on a silicon circuit combining the MEMS process on the ASIC process in a single die. This microphone targets high-end consumer applications: notebooks, laptops...

**Epcos T4060**
Manufactured in the EPCOS “Chip Size MEMS Package” technology, the component targets high-end consumer applications: mobile phones, MP3 players and digital cameras.

**Knowles SPU0410LR5H**
It uses free floating diaphragm with capacitive sensing. It is the 4th generation of MEMS microphones from Knowles. This device is found in high volume consumer applications: cell & smart phones (iPhone 4)...

**Analog Devices ADMP421**
It uses a free floating diaphragm and a capacitive sensor and offers a full integration of a MEMS microphone & ASIC. It targets high-end consumer applications: tablets, smart phones.

**AAC Acoustic iPhone 4**
This MEMS Microphone uses a free floating diaphragm & a capacitive sensing and offers a full integration of a MEMS microphone and ASIC, both provided by Infineon. It is for consumer applications: cell & smart phones...

**STM MP45DT01**
The MP45DT01 microphone uses a MEMS die manufactured by Omron using a free floating diaphragm, and a capacitive sensing. It is for high-end consumer applications: notebook, tablets...

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David Jourdan - jourdan@yole.fr
Le Quartz, 75 Cours Emile Zola - 69100 Villeurbanne - Lyon - FRANCE
AKU1126 MICROPHONES

GENERAL DESCRIPTION

The AKU1126 is the world’s smallest, analog-output microphone that uses standard semiconductor packaging technology and materials. While other microphones degrade in performance as they shrink in size, the AKU1126 maintains superior performance in an ultra-small form factor.

The AKU1126’s gain select feature, accessed by use of a single external resistor, allows the microphone to be used in both near-ear applications as well as far-field applications - such as speaker phones or headsets - without the use of additional amplifiers.

The AKU1126 is the first microphone product to leverage Akustica’s 1mm x 1mm CMOS MEMS microphone die – a monolithic solution which integrates the acoustic transducer and accompanying electronics in a single chip of silicon. In contrast to other silicon microphones, Akustica’s one die approach eliminates the need for inter-die wirebonds, allowing for smaller, higher performance, more reliable products.
AKU1126 MICROPHONE

1mm x 1mm MEMS Chip
POSSIBLE MICROPHONE STRUCTURE

FIG. 21

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LAYOUT AND CROSSECTION FOR RIT MICROPHONE
DIAPHRAGM EXAMPLE CALCULATIONS

Diaphragm
  20 mm diameter
  50 um thickness
  Aluminum foil material

Baking plate
  rigid copper PCB
  9 vent holes
  air gap = double sided tape ~50um
  thickness around outer ring

Pressure is ~0.1Pa or ~0.15E-4 lb/in2

DC voltage 5 volts
# Table of Pressure Conversions

1 atm = 14.696 lbs/in\(^2\) = 760.00 mmHg  
1 atm = 101.32 kPa = 1.013 \times 10^6 \text{ dynes/cm}^2  
1 \text{ Pascal} = 1.4504 \times 10^{-4} \text{ lbs/in}^2 = 1 \text{ N/m}^2 = 10 \text{ dyne/cm}^2  

1 \text{ SPL (Sound Pressure Levels)} = 0.0002 \text{ dynes/cm}^2  
Average speech = 70 \text{ dB}_{\text{SPL}} = 0.645 \text{ dynes/cm}^2  
Pain = 130 \text{ dB}_{\text{SPL}} = 645 \text{ dyne/cm}^2  
Whisper = 18 \text{ dB}_{\text{SPL}} = 1.62 \times 10^{-3} \text{ dyne/cm}^2
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To use this spreadsheet enter values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The results are displayed in the purple boxes.

### Diaphragm

<table>
<thead>
<tr>
<th>Deflection $Y_{max} = 0.0151 P L^4 (1 - \nu)^3 / E H^3$</th>
<th>$Y_{max} = \text{2.61E-02 , \mu m}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P =$ Pressure</td>
<td>$P =$ 1.50E-05 lbs/in$^2$</td>
</tr>
<tr>
<td>$L =$ Length of side of square diaphragm</td>
<td>$L =$ 20000 $\mu m$</td>
</tr>
<tr>
<td>$E =$ Youngs Modulus</td>
<td>$E =$ 6.80E+10 N/m$^2$</td>
</tr>
<tr>
<td>$\nu =$ Poissons Ratio</td>
<td>$\nu =$ 0.33</td>
</tr>
<tr>
<td>$H =$ Diaphragm Thickness</td>
<td>$H =$ 50 $\mu m$</td>
</tr>
<tr>
<td>$P =$ Diaphragm Thickness</td>
<td>$P =$ 1.03E-01 Pascal</td>
</tr>
</tbody>
</table>

### Diaphragm

<table>
<thead>
<tr>
<th>Stress $= 0.3 P (L/H)^2$ (at center of each edge)</th>
<th>Stress $= \text{4.96E+03 Pascal}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P =$ Pressure</td>
<td>$P =$ Yield Strength $= \text{1.70E+08 Pascal}$</td>
</tr>
<tr>
<td>$L =$ Square Diaphragm Side Length</td>
<td></td>
</tr>
<tr>
<td>$H =$ Diaphragm Thickness</td>
<td>1N/m$^2$ = 1 Pascal = 10dyne/cm$^2$</td>
</tr>
</tbody>
</table>

### Two Parallel Plates

<table>
<thead>
<tr>
<th>Capacitance $= \varepsilon \varepsilon_0 \text{Area} / d$</th>
<th>$C =$ 5.56E-11 F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_0 =$ Permittivity of free space $= 8.85E-14$ F/cm</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon_r =$ relative permittivity $= 1$ for air</td>
<td></td>
</tr>
<tr>
<td>Area $= \text{3.14E+00 cm}^2$</td>
<td></td>
</tr>
<tr>
<td>$d =$ distance between plates</td>
<td></td>
</tr>
<tr>
<td>If round plates, Diameter $= 20000 \mu m$</td>
<td></td>
</tr>
<tr>
<td>If square plates, Side $= 0 \mu m$</td>
<td></td>
</tr>
<tr>
<td>Capacitance Change for $Y_{max}$ Deflection $= 2.90E-14$ F</td>
<td></td>
</tr>
</tbody>
</table>

### Two Parallel Plates

<table>
<thead>
<tr>
<th>Electrostatic Force $= \varepsilon \varepsilon_0 \text{Area} V^2 / 2d$</th>
<th>$F_{elec} =$ 1.39E-05 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V =$ applied voltage</td>
<td>$V =$ 5 volts</td>
</tr>
<tr>
<td>Single Plate</td>
<td></td>
</tr>
<tr>
<td>Pressure Force $= \text{Pressure} \times \text{Area}$</td>
<td>$F_{\text{press}} =$ 4.14E-05 N</td>
</tr>
</tbody>
</table>

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Microphone Design

LAYOUT FOR PCB MICROPHONE DEMO

3” x 3” PCB
Microphone Diameter = 20 mm
**SIGNAL CONDITIONING**

Co = Average value of C
Cm = amplitude of C change
C = Co + Cm sin (2πft)
V is constant across C

\[ i = \frac{d(CV)}{dt} \]
\[ i = V \cdot C_m \cdot 2\pi f \cdot \cos(2\pi ft) \]

\[ Vo = -2\pi f \cdot V \cdot R \cdot C_m \cdot \cos(2\pi ft) \]

Amplitude of Vo
**EXAMPLE CALCULATIONS**

\[
V_0 = - i R = - 2\pi f V R C_m \cos (2\pi ft)
\]

Let \( f = 5 \text{ Khz}, \ V = 5, \ C_m = 100fF, \ R = 1\text{ MEG} \)

\[
V_0 = -0.0157 \cos (2\pi ft) \text{ volts}
\]

(15.7 mV amplitude sinusoid)

Amplitude of \( V_0 = - 2\pi f V R C_m \)

Predicted Frequency Response
PICTURES OF FABRICATED PCB MICROPHONE

Back

Front
MEASURED CAPACITANCE RESULTS

HP LCR Meter

Measured Capacitance 54\text{pF}
Calculated = 56 \text{pF}

Puff of air causes 100’s of f\text{F} capacitance change
Calculated = 100’s f\text{F}
MAKING THE LOW NOISE AMPLIFIER

V = +/- 9 Volts, R = 5.6 MEG

http://people.rit.edu/lffeee/Tones.wmv

Click to Play Tones.wav

Speaker

Microphone
MOVIE OF MICROPHONE AND AMP OUTPUT

Vout = \sim 20\text{mV p-p}

http://people.rit.edu/lffeee/RITMicrophone.wmv
### MEASURED VOUT VS FREQUENCY (HZ)

<table>
<thead>
<tr>
<th>Freq (Hz)</th>
<th>Vout (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>16</td>
</tr>
<tr>
<td>750</td>
<td>24</td>
</tr>
<tr>
<td>1000</td>
<td>30</td>
</tr>
<tr>
<td>1500</td>
<td>32</td>
</tr>
<tr>
<td>2000</td>
<td>34</td>
</tr>
<tr>
<td>3000</td>
<td>40</td>
</tr>
<tr>
<td>4000</td>
<td>50</td>
</tr>
<tr>
<td>5000</td>
<td>22</td>
</tr>
</tbody>
</table>

- **Graph**:
  - X-axis: Frequency (Hz)
  - Y-axis: Vout (mV)
  - The graph shows a peak around 4000 Hz with decreasing values as frequency increases or decreases.
VOICE RECORDING

\[ R = 5.6 \text{ MEG} \]

\[ C_c = 1 \text{uF} \]

\[ 2K \]

\[ V = 9 \text{ V} \]

RIT Microphone

Voice Capture & Editing Software
SINGLE SUPPLY VERSION OF SIGNAL PROCESSING

Vdc=9V

TL081

5.6 MEG

Vo

100K

100K

earth ground

TL081, TL081A, TL081B
D, JG, P, OR PW PACKAGE
(TOP VIEW)

OFFSET N1
1
8
NC

IN–
2
7
VCC+

IN+
3
6
OUT

VCC–
4
5
OFFSET N2

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The analog output was obtained for various frequency audio tones generated using speakers connected to a personal computer. The amplified microphone output voltage was measured at various frequencies. The microphone was used to make a voice recording.
REFERENCES

1. Journal of Microelectromechanical Systems, IEEE

2. Acustica

1. Write an expression for the output of the single supply version of the capacitor microphone amplifier circuit.

2. Make an accurate calculation of the microphone capacitance, change in capacitance and amplifier output voltage for pressures corresponding to loud speech. Let $V = 9$ volts, $R = 5.6$ MEG and $f=2000$ hz.

3. “Mr. Watson… come here … I want to see you” is a famous statement. Who made this statement, when and why.

4. Find a data sheet for a commercial MEMS microphone. What is the sensitivity at 2000 Hz, what is the price for small quantities.