A Low Noise CMOS Amplifier for a Piezoelectric MEMS Microphone

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Outline

- Motivation for piezoelectric microphones
- Microphone implementation
- Design challenges and specifications
- Differential difference low noise amplifier (DDLNA)
- DDLNA sizing optimization
- DDLNA results
- Self-biased Vth referenced current bias
- Conclusion
Motivation

- Microphones are one of the fastest growing applications of MEMS – use capacitive transduction

- Piezoelectric transduction
  - Advantages: Linearity, fabrication simplicity
  - Disadvantage: High noise – circuitry limited

  The results in Fig. 5 indicate that most of the noise in the output can be ascribed to the amplifier. From Fig. 5, the input-referred, A-weighted noise is approximately 60 nV. Since an operational amplifier with gain set to 1000. As system level optimization has not yet been done, noise floor performance is subsequently dominated by the amplifier circuitry.

[Fazzio 2007]

[Leoppert]

[Kim 1991]
### Design Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (Low)</td>
<td>-42 dB re 1V/Pa</td>
<td>dB re 1 V/Pa</td>
</tr>
<tr>
<td>Sensitivity (High)</td>
<td>-22 dB re 1V/Pa</td>
<td></td>
</tr>
<tr>
<td>Output Impedance</td>
<td>&lt;100</td>
<td>Ω</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt;800</td>
<td>μW</td>
</tr>
<tr>
<td>Noise Floor</td>
<td>&lt;40</td>
<td>dBA</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>2.5</td>
<td>V</td>
</tr>
<tr>
<td>THD</td>
<td>&lt;1% at 100dB SPL</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>&lt;10% at 115dB SPL</td>
<td></td>
</tr>
</tbody>
</table>

- Specifications borrowed from those for the Knowles Sisonic Microphone
Microphone Design

- Microphone consists of several piezoelectric elements that can be wired in series or parallel.
- Mechanical system decoupled from electrical system via conservation of energy:

\[ V_0, C_0 \]
\[ V_0, 2C_0 \]
\[ V_0, C_0 \]
\[ V_0, C_0 \]

\[ V^2C = V_0^2 2C_0 \]
\[ V^2C = 4V_0^2 C_0 / 2 \]

- Total output energy = 4.9e-18 J/Pa
- Capacitance = 5 – 56 pF for differential signaling
Microphone Self Noise

- Microphone noise dominated by electrical loss in the piezoelectric film [Levinzon 2004]:
  - Dissipation factor: \( \tan(\delta) = \frac{1}{\omega R C_{\text{Mic}}} = 0.002 \) [Dubios 1999]
A-Weighted Noise

Threshold of Hearing

Communication Starts Becoming Difficult

Hazard to Hearing From Continuous Exposure

Jet Aircraft 250 m Overhead

Heavy Truck at 40 km/h 7m distance

Passenger Car at 60 km/h 7m distance

Busy General Office

Quiet Bedroom

Most Piezoelectric Microphones

Cell Phone Microphones

Threshold of Pain

Low Noise Amplifier Designs

- Dominant noise sources are transistor flicker noise and channel noise

- Differential amplifier w/ feedback
  - Lower input impedance
  - Resistor mismatch reduces CMRR

- Differential common source input into amplifier in feedback
  - Resistor mismatch leads to mismatch in common mode voltage
  - Area and power overheads
  - Increased complexity
Differential Difference Amplifier

- High input impedance
- Relatively few devices
- Noise from both PMOS and NMOS devices – about equal in optimal design
Differential Difference Low Noise Amp
Sizing Optimization

We minimized distortion, power and area
DDA Noise Analysis

Amplifier contributes a negligible amount of noise
Extracted Sim with Process Variation

Max distortion specification must be relaxed
Self-biased $V_{th}$ Referenced Current

$$V_{GS} = I_R \times R_1$$
$$= V_{DSATM1} + V_{THM1}$$
$$= \sqrt{\frac{2I_L}{\mu C_{OX} \frac{W}{L} M1}} + V_{THM1}$$

$$I_R = \frac{V_{THM1}}{R_1}$$

Current is referenced to $V_{th}$ of M1
Current Reference Performance

Current reference rejects supply noise
Layout

a) Differential difference LNA  b) Reference current
## Results

<table>
<thead>
<tr>
<th>Specification</th>
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<th>Simulated</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>Sensitivity (Low)</td>
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<td>-22</td>
<td></td>
</tr>
<tr>
<td>Output Impedance</td>
<td>&lt;100</td>
<td>99</td>
<td>Ω</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt;800</td>
<td>534</td>
<td>μW</td>
</tr>
<tr>
<td>Noise Floor</td>
<td>&lt;40</td>
<td>39.8</td>
<td>dBA</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>2.5</td>
<td>2.5</td>
<td>V</td>
</tr>
<tr>
<td>THD</td>
<td>&lt;1%</td>
<td>0.042%</td>
<td>% at 100dB SPL</td>
</tr>
<tr>
<td></td>
<td>&lt;10%</td>
<td>9.167%</td>
<td>% at 115 dB SPL</td>
</tr>
</tbody>
</table>
Comparison to Other Work

- AD621 [Fazzio 2007] – noise about equal but signal degradation would result from high input capacitance

- ZnO Microphone [Ried 1993] – order of magnitude higher amplifier noise limits noise floor
Conclusions

- Piezoelectric microphones can suitably meet the design specifications for consumer electronics applications
- They are less expensive to fabricate and have better linearity than capacitive microphones
- DDLNA provides a low noise, low distortion solution with a high input impedance
- Our circuit is a low power, low area solution