A CMOS Digitally Controlled, Low Power, Variable Gain Headphone Amplifier

December 5, 2007

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Introduction

• Application
• Goals
• Topology
• Simulation Results
• Conclusion
**General Use**

- Amplify the signal output by a small music device
- Connect between device and a set of headphones
- Adjustable volume control
Project Goals

- Variable gain – 0dB to 20dB
- Low total power consumption
- Matched input / output impedance
- Bandwidth typical for audio applications
- Maximum input signal = 50 mV
- Total harmonic distortion < 1%
Topology

• Current generation stage
• Input stage
• Variable gain stage
• Output stage
**Current Source / Bias Generation Stage**

- Supplies current to each stage
- Supplies desired voltage bias
- Supplies gate voltages
- Keeps transistors in saturation
- Headroom considerations
The Input Stage

- Common gate with degeneration topology
- Sets input impedance
  - Typical headphone impedance: 75-150 Ohms
- Generates Gain (~23dB)
- $\text{Rin} = 1/gm1$
- Gain = $(gm1 + gmb1) / gm2$
Volume Control Stage

- Allows the overall gain to be adjusted from 0dB to 20dB
- Gain is changed by switching the amount of current driven through the stage
- The switching is done by a digital control
- Common source with degeneration topology
- Gain = \(-gm\times R_d/(1+gm\times R_s)\)
The Output Stage

- Source follower topology
- A buffer stage
- Used to set the output impedance
  - Typical headphone impedance: 75-150 Ohms
- Rout = 1/gm
- Gain = gm/ (gm+gmb)
  - Approximately –3dB
- Input stage compensates for drop in gain
## Simulation Results

**Gain for each Volume Level**

<table>
<thead>
<tr>
<th>3-Bit Volume Control Level</th>
<th>Gain (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-0.271 to 0.513</td>
</tr>
<tr>
<td>1</td>
<td>2.85</td>
</tr>
<tr>
<td>2</td>
<td>5.71</td>
</tr>
<tr>
<td>3</td>
<td>8.57</td>
</tr>
<tr>
<td>4</td>
<td>11.42</td>
</tr>
<tr>
<td>5</td>
<td>14.28</td>
</tr>
<tr>
<td>6</td>
<td>17.14</td>
</tr>
<tr>
<td>7</td>
<td>19.78</td>
</tr>
</tbody>
</table>

![Gain with Digital Volume Control](image-url)
Simulation Results

Linearity

Vout (V) vs. Vin (V)

Ideal

Measured
## Simulation Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Supply</td>
<td>2.5 V</td>
<td>2.5 V</td>
</tr>
<tr>
<td>Current Supply</td>
<td>100 uA</td>
<td>100 uA</td>
</tr>
<tr>
<td>Max Gain</td>
<td>20 dB</td>
<td>19.78 dB</td>
</tr>
<tr>
<td>Min Gain</td>
<td>0 dB</td>
<td>-0.2711 to 0.513 dB</td>
</tr>
<tr>
<td>Input Impedance</td>
<td>100 Ω</td>
<td>98.38 Ω</td>
</tr>
<tr>
<td>Output Impedance</td>
<td>100 Ω</td>
<td>100.3 Ω</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>100 Hz to 23 KHz</td>
<td>100 Hz to 23 KHz</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt; 6 mW</td>
<td>3.77 mW</td>
</tr>
<tr>
<td>Max Input Signal</td>
<td>50 mV</td>
<td>40 mV (for linearity)</td>
</tr>
<tr>
<td>THD</td>
<td>&lt; 1% (at max gain)</td>
<td>0.7537% (1mV input)</td>
</tr>
</tbody>
</table>
## Simulation Results

### Process Corners Variation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TT</th>
<th>FF_0°C</th>
<th>FF_75°C</th>
<th>SS_0°C</th>
<th>SS_75°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gain (at max volume)</strong></td>
<td>19.78dB</td>
<td>21.73dB</td>
<td>19.02dB</td>
<td>19.5dB</td>
<td>2.568dB</td>
</tr>
<tr>
<td><strong>Input Impedance</strong></td>
<td>98.38 Ω</td>
<td>80.46 Ω</td>
<td>113.4 Ω</td>
<td>89.85 Ω</td>
<td>500.1 Ω</td>
</tr>
<tr>
<td><strong>Output Impedance</strong></td>
<td>100.3 Ω</td>
<td>86.85 Ω</td>
<td>107.3 Ω</td>
<td>96.69 Ω</td>
<td>119.7 Ω</td>
</tr>
<tr>
<td><strong>Power Consumption</strong></td>
<td>3.77mW</td>
<td>3.851mW</td>
<td>3.798mW</td>
<td>3.724mW</td>
<td>3.66mW</td>
</tr>
</tbody>
</table>
Simulation Results
DRC and LVS Clean
Conclusion

- The circuit simulations match our goals
- Only the maximum input signal was affected by linearity
- We based our design on the specifications of other common headphone amplifiers