High-Level Power Management of Audio Power Amplifiers for Portable Multimedia Applications

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Outline

- Introduction
- Background
  - Measurement setup
  - Loudspeaker characteristics
  - Audio power amplifiers characteristics
- Loudspeaker-aware low-power filtering
- Experimental results
- Conclusions
Modern portable multimedia devices have high-quality displays and provide high-fidelity audio output.
Related work

  - Power-quality trade-off
  - A low-power MPEG decoder

  - Power-quality trade-off
  - Reducing the bandwidth of the audio signal

- Previous high-level power reduction technique for audio subsystems
  - Focus on reducing the audio processing
  - Did not consider the audio power amplifier, which is the most part of the audio power consumption
In-house platform for the audio power amplifier power management
- Class-AB: TPA0222PWP
- Class-D: TPA2000D2PWPR
- Differential amplifier: Burr-Brown PGA204BU
Measurement Setup

- Logging the current and the voltage
  - Intelligent Instrument UDAS1001E USB data acquisition system
  - Fluke 87V trueRMS digital multimeter
  - TDS3052B Tektronix digital storage oscilloscope (500MHz and 5GS/s)

- SPL (Sound Pressure Level) measurement
  - To be free from ambient interference
    - Measured at night in remote desert area
    - Extremely quiet and superior to standard closed acoustic chamber
  - Audio-Technica AT4040 high-performance condenser microphone
    - Sound ranging from 20Hz to 20KHz with a fairly flat frequency response
  - Extech407730 sound pressure lever meter
Characteristics

- Loudspeaker
- Audio power amplifier
Characteristics: Loudspeakers

- Structure of a magnetic loudspeaker
  - The other types are rarely found in portable applications

- The voice coil is the only electric component
Characteristics: Loudspeakers

- Voice coil
  - Inductor with a non-zero resistance
- Resonant behavior of the loudspeaker
  - If the frequency of the voltage across the voice coil matches the resonant frequency of the cone and voice coil, the loudspeaker exhibits its resonant impedance
Characteristics: Loudspeakers

- Loudspeaker units

<table>
<thead>
<tr>
<th></th>
<th>GC0301K</th>
<th>GC0351P-1</th>
<th>GC0401S</th>
<th>GF0668</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>16mm X 30mm</td>
<td>16mm X 35mm</td>
<td>20mm X 40mm</td>
<td>66mm X 66mm</td>
</tr>
<tr>
<td>SPL</td>
<td>77dB</td>
<td>82dB</td>
<td>89dB</td>
<td>90dB</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>500 Hz~4 KHz</td>
<td>630 Hz~13 KHz</td>
<td>550 Hz~12 KHz</td>
<td>300 Hz~20 KHz</td>
</tr>
</tbody>
</table>

- SPL: 0.5 meter distance measurement (from data sheets)
Characteristics: Loudspeakers

- The resonant region
  - Power amplifier consumes the least power
  - The SPL is the highest
- Below the resonant region
  - No audible sound output (for the same input amplitude)
  - The region with the lowest impedance, because of the inductive negligible reactance
- Linear region
  - The resonant effect decreases
- Beyond the linear region
  - No audible sound output
  - The power consumption in this upper region is much smaller than that in the region below the resonant region
**Characteristics: Loudspeakers**

- Resonant region
- Below the resonant region
- Linear region
- Beyond the linear region

![Graphs showing loudspeaker characteristics](image)

- **V**: Speaker RMS voltage
- **S**: Sound pressure level (SPL) @ C weighting
- **Ω**: Speaker impedance
- **A**: Speaker RMS current
Characteristics: Amplifiers

Audio power amplifiers

- **Class-A**
  - The least distortion and the most linear
  - Bias current flowing to the output at all times
  - The most wasteful power consumption (about 20% efficiency)

- **Class-C, class-E and class-F**
  - Non-linear amplifiers
  - The most power efficient design (over 90% efficiency)
  - Designed for high frequency radio signals (not for audio applications)

- **Class-AB**
  - Combines advantages of the class-A and class-B amplifiers
  - In place of the class-B amplifier
  - Most common type of power amplifiers

- **Class-D**
  - Converts audio signals into pulse width modulated signals
  - Significantly reduces the power loss
**Characteristics: Amplifiers**

- **Power efficiency of an audio power amplifier**

  \[ \eta_A = \frac{P_L}{P_A} \]

  where,

  - \( P_L \): the power consumed by the loudspeaker
  - \( P_A \): the power consumed by the power amplifier
  - \( \eta_A \): the efficiency of the power amplifier

- **Measured power amplifier efficiency**
  - **Class-AB: TPA0222PWP**
    - Significantly varies with the output power
    - 100mW @1KHz output: 20%
    - 1W @1KHz output: 40%
  - **Class-D: TPA2000D2PWPR**
    - Near uniform efficiency over the wide range of the output power
    - 100mW @1KHz output: 64.5%
    - 1W @1KHz output: 67.8%
Loudspeaker-Aware Low-power Filtering

- **Power waste**
  - Modern portable systems play high-fidelity digital audio source (20Hz~22KHz)
  - Miniature loudspeakers have quite a narrow bandwidth
  - Thus, the power amplifier wastes a significant amount of power in driving loudspeaker, but produces no sound
  - Especially in the range from 20Hz to near the resonant frequency, the waste amount of the total amplifier power consumption is around 20%~40%
Loudspeaker-Aware Low-power Filtering

- Power efficiency of the SPL

\[ \eta_S(f) = \frac{S(f)}{P_A(f)} = \eta_A \frac{S(f)}{P_L(f)} \]

where,
- \( S(f) \): the SPL at the input signal frequency \( f \)
- \( P_L(f) \): the power consumed by the loudspeaker
- \( P_A(f) \): the power consumed by the power amplifier
- \( \eta_A \): the efficiency of the power amplifier

- \( \eta_S \) is independent of the input signal amplitude
- Filtering with cut-off frequency determined by \( \eta_S \)
Loudspeaker-Aware Low-power Filtering

- The built-in miniature loudspeakers
  - Loudspeaker-aware low-power filtering is activated

- The headphone
  - Headphones offer far better bandwidth performance
  - Higher impedance (an order of magnitude higher impedance than the loudspeakers) allows lower power consumption in the power amplifier
  - No filtering

- The external speakers
  - External power sources are often available as well
  - No filtering in this case
Experimental Results

- Three different types of sound sources
  - Movie sound track
    - A beautiful mind
  - Pop music
    - Abba, Lay all your love on me
  - Classic music
    - Beethoven Symphony No.5 in c minor

- Using an iPod shuffle as a player

- Cut-off frequencies for the low-power filtering
  - Determined by $\eta_s$ : select the threshold value
    - GF0668: 200Hz
    - GC0401S: 500Hz
    - GC0351P-1: 600Hz
    - GC0301K: 600Hz
## Experimental Results

<table>
<thead>
<tr>
<th>Amplifier</th>
<th>Loudspeaker</th>
<th>Cut-off frequency</th>
<th>SNR (dB)</th>
<th>Power saving: mW (%)</th>
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<td>High</td>
<td>Movie</td>
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Loudspeakers are sorted by this order.
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- **average power consumption = 305 mW**
- **average power consumption = 142 mW**

- Audio power output for the experimental setup
  - Maximum peak output around 1W
  - Wide dynamic ranges of the sound sources limit the average audio output at a few hundred mW
  - The class-AB consumes more power than class-D
## Experimental Results: SNR

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Since the classic music contains wider range of frequency spectrums,

![Bar chart showing SNR for different amplifiers and loudspeakers](image)

- **Class-AB**
- **Class-D**
## Experimental Results: Power Saving

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### Graphs
- **Class-AB**
- **Class-D**

The graphs show the power saving in different modes (Movie, Pop, Classic) for both Class-AB and Class-D amplifiers, with various loudspeakers (GF0668, GC0401S, GC0351P-1, GC0301K). Power saving is measured as a percentage, with distinct bars for each amplifier type and speaker model.
Conclusions

- Audio power amplifiers are primary power consumers of portable multimedia systems
  - So far, previous work focused on the audio signal processing power

- The proposed technique can save 20% to 35% of audio amplifier power consumption without any appreciable degradation of sound fidelity
  - Cutting off input signals below the resonant region

Future work
- Context-based filtering
  - Use different cut-off frequencies by the type of sound sources automatically
Q&A

- Demo will be shown in next poster session