Power Solutions for Class-D Audio Amplifiers
Power Solutions for Class-D Audio Amplifiers

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Agenda

• Part 1 – Audio basics
  – Class-D versus Class-A/-AB
  – Impedance of speakers
  – Crest factor

• Part 2 – Impact of power supply on audio performance
  – Definition
  – Cause of audio quality degradation
  – Power supply output impedance

• Part 3 – AC/DC power supply (PMP10215)

• Part 4 – Automotive power supply (PMP11769)

• Conclusion
Part 1
Audio Basics
Working Theory Class-A/-AB

<table>
<thead>
<tr>
<th>Class-A</th>
<th>Class-B “Push-Pull”</th>
<th>Class-AB “Push-Pull”</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Class-A Diagram" /></td>
<td><img src="image2" alt="Class-B Diagram" /></td>
<td><img src="image3" alt="Class-AB Diagram" /></td>
</tr>
</tbody>
</table>

Transistor conducts for full waveform
Both transistors conduct for less than half of waveform
Both transistors conduct slightly more than half of waveform

Heavy biasing needed to keep transistor in linear region
No biasing needed, but signal distortion at zero-crossing
Crossover distortion is greatly reduced by biasing

Highest linearity, lowest $\eta$
Crossover distortion, good $\eta$
High linearity, moderate $\eta$
Working Theory Class-D

- Works like a synchronous buck converter
  - Audio input instead of fixed voltage reference
- Duty-cycle changes with input signal, average is 50%
- Negative feedback to compensate for bus voltage variations and to improve linearity
- Main reason for losses is switching losses of FETs, especially at high supply voltages
- Efficiency up to 90%
  - Class-G: Class-D with adaptive supply voltage to increase efficiency further
# Class-D Configurations

<table>
<thead>
<tr>
<th>Single-Ended (SE)</th>
<th>Bridge-Tied Load (BTL)</th>
<th>Parallel BTL (PBTL)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Single-Ended" /></td>
<td><img src="image2.png" alt="Bridge-Tied Load" /></td>
<td><img src="image3.png" alt="Parallel BTL" /></td>
</tr>
<tr>
<td><strong>Speaker between one half-bridge and GND</strong></td>
<td><strong>Speaker between two half-bridges (full-bridge)</strong></td>
<td><strong>Two full-bridges (BTL) in parallel</strong></td>
</tr>
<tr>
<td>- Swing of $\frac{1}{2}$ of supply voltage</td>
<td>- Inverted driving of the second half-bridge</td>
<td>- Same voltage swing as for BTL</td>
</tr>
<tr>
<td>- $\frac{1}{2}$ of supply voltage after LC filter $\rightarrow$ DC blocking capacitor</td>
<td>- Full supply voltage swing $\rightarrow$ 4x power of SE</td>
<td>- Double the current as for BTL $\rightarrow$ 8x power of SE</td>
</tr>
</tbody>
</table>

For multi-channel systems with moderate power:
- Higher power and 4 Ω to 8 Ω impedance
- High-power subwoofers with 2 Ω impedance
Loudspeaker Impedance

- Indication of speaker’s AC resistance
- Nominal impedance is usually determined at lowest point after resonance
- Trend to higher impedances to reduce weight of wire harness
- Critical to use low impedance speakers on high impedance amplifiers
- Impedance compensation needed when using passive crossovers (multi-way speakers)
  → Impedance can be linearized with Zobel network

Typical Impedances
- Car Hi-Fi: 2 Ω, 4 Ω
- Home Audio: 4 Ω, 6 Ω, 8 Ω, 16 Ω
Crest Factor

- Ratio between peak and RMS power level
- Audio compressors decrease dynamic range of audio signal by reducing peaks
  - Lowers crest factor
  - Music sounds louder
  - Balances volume (broadcast)

\[ C = \frac{P_{\text{PEAK}}}{P_{\text{RMS}}} \]

\[ C_{dB} = 20 \cdot \log_{10} \left( \frac{P_{\text{PEAK}}}{P_{\text{RMS}}} \right) \]

<table>
<thead>
<tr>
<th>Signal</th>
<th>Crest Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient noise</td>
<td>3 : 1</td>
</tr>
<tr>
<td>Speech</td>
<td>4 : 1</td>
</tr>
<tr>
<td>Music with peak level</td>
<td>4 : 1 to 8 : 1</td>
</tr>
<tr>
<td>compression</td>
<td></td>
</tr>
<tr>
<td>Music without peak level</td>
<td>8 : 1 to 10 : 1</td>
</tr>
<tr>
<td>compression</td>
<td></td>
</tr>
<tr>
<td>Movie audio</td>
<td>&gt;10 : 1</td>
</tr>
</tbody>
</table>
Power Supply – Average vs. Peak Power

The average and peak power capabilities of the power supply directly correspond to the crest factor of the signal.

<table>
<thead>
<tr>
<th>Average Power of Power Supplies Defines</th>
<th>Peak Power of Power Supplies Defines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average current capability</td>
<td>Peak current capabilities</td>
</tr>
<tr>
<td>Thermal interface</td>
<td>Current limit</td>
</tr>
<tr>
<td>Component packages</td>
<td>Saturation current of PFC and output inductor</td>
</tr>
<tr>
<td>RMS parameters of magnetic components</td>
<td>Peak current capability of FETs and diodes</td>
</tr>
</tbody>
</table>
Part 2
Impact of Power Supply on Audio Performance
Definition of Audio Performance

- **Total harmonic distortion** (THD) is the parameter to measure and compare audio performance

\[
THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_N^2}}{V_1}
\]

- Total THD of amplifier around 0.1% for mediocre systems, <0.025% for high-quality systems
- Down to 0.1% THD → Maximum acceptable performance degradation due to low cost optimization

<table>
<thead>
<tr>
<th>Transient Distortion</th>
<th>Frequency Response</th>
<th>Output Impedance</th>
<th>PSRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>![ transient_distortion ]</td>
<td>![ frequency_response ]</td>
<td>![ output_impedance ]</td>
<td>![ psrr ]</td>
</tr>
</tbody>
</table>

- 0.1% is maximum THD most people won’t hear

\[
V_N \cdot \text{RMS voltage of } N\text{th harmonic}
\]

\[
V_1 = \text{Fundamental frequency}
\]
Cause of Audio Degradation – Ripple

- Ripple frequency at twice audio frequency in BTL
- 250 Hz power supply ripple $e(s)$ causes modulation with audio signal and increases THD
- Closed-loop amplifier has high PSRR thanks to $L(s)$
- High frequency ripple has no impact as modulation products are outside audio band

$$e(s)$$

OpenLoopGain = $L(s) = G(s) \cdot H(s)$
Cause of Audio Degradation (cont’d)

• TPA3251 EVM in BTL, 36.0 V $V_{PD}$ supply voltage
• 0.4 kHz, 2.5 kHz and 5 kHz test frequencies
• 2 channels with 50 W$_{RMS}$ each (14.14 V$_{RMS}$ @ 4 $\Omega$ load)
• 2 $\Omega$ equivalent impedance in series between PSU and amplifier

<table>
<thead>
<tr>
<th>0 $\Omega$ Resistor</th>
<th>2 $\Omega$ Resistor</th>
</tr>
</thead>
<tbody>
<tr>
<td>F (kHz)</td>
<td>THD CH1</td>
</tr>
<tr>
<td>0.4</td>
<td>0.00190</td>
</tr>
<tr>
<td>2.5</td>
<td>0.00716</td>
</tr>
<tr>
<td>5.0</td>
<td>0.01092</td>
</tr>
</tbody>
</table>
Cause of Audio Degradation – Clipping

- Supply voltage too low causes clipping as duty-cycle becomes too high
- Dangerous for tweeters due to high energy (thermal) in high frequency range
- Dangerous for subwoofers due to
  - Mechanical limit of speaker’s swing ($P_{AMPLIFIER} > P_{SPEAKER}$)
  - Electrical limit of speaker’s coil (thermal)
- Class-G for adjustable supply voltage needs to be managed to avoid clipping

![Diagram showing large supply voltage ripple causing clipping](image)

![Graph showing 1 kHz square wave harmonic content](image)
PSU Output Impedance – Ripple

- Closing the loop improves output impedance by open-loop gain:
- In our case, closed-loop output impedance $|Z_{OUT}(s)| = 2 \, \Omega$ (6 dBΩ)
- At crossover frequency ($f_{CO}$) output impedance is close to output capacitor impedance $X_{C(OUT)}(f) \rightarrow X_{C(OUT)}(f_{CO}) \leq 2 \, \Omega$

$$Z_{OUT(ClosedLoop)}(s) = \frac{Z_{OUT(OpenLoop)}(s)}{1+L(s)}$$
PSU Output Impedance – Transient

Transient response affects $V_{\text{OUT}}$ regulation during large load variations

- Bandwidth of PSU ($f_{\text{CO}}$) and output capacitor determines this behavior ($t_p = \frac{1}{4} f_{\text{CO}}$)
- Calculate $C_{\text{OUT}}$ as highest value from undershoot and overshoot

<table>
<thead>
<tr>
<th>Calculation of Minimum Output Capacitance $C_{\text{OUT}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current mode</strong> (critically damped)</td>
</tr>
<tr>
<td>$C_{\text{OUT}} \geq \frac{\Delta I}{e \cdot \pi \cdot f_{\text{CO}} \cdot \sqrt{\Delta V_{\text{UNDERSHOOT}}^2 - (R_{\text{ESR}} \cdot \Delta I)^2}}$</td>
</tr>
<tr>
<td><strong>Voltage mode</strong></td>
</tr>
<tr>
<td>$C_{\text{OUT}} \geq \frac{\Delta I}{8 \cdot f_{\text{CO}} \cdot \sqrt{\Delta V_{\text{UNDERSHOOT}}^2 - (R_{\text{ESR}} \cdot \Delta I)^2}}$</td>
</tr>
<tr>
<td><strong>Overshoot</strong></td>
</tr>
<tr>
<td>$C_{\text{OUT}} \geq \frac{L_{\text{OUT}} \cdot \Delta I^2}{(V_{\text{OUT}} + \Delta V_{\text{OVERSHOOT}})^2 - V_{\text{OUT}}^2}$</td>
</tr>
</tbody>
</table>

Nominal voltage

- $V_{\text{OUT}} = P V_{\text{DD(NOM)}}$

$P V_{\text{DD}}$ headroom

- $\Delta V_{\text{OVERSHOOT}} \leq P V_{\text{DD(ABSMAX)}} - P V_{\text{DD(NOM)}}$

Avoid clipping

- $\Delta V_{\text{UNDERSHOOT}} = P V_{\text{DD(NOM)}} - P V_{\text{DD(CLIPPING)}}$
Part 3
AC/DC Power Supply
Specification

- Universal input $85 \text{ V}_{\text{AC}}$ to $264 \text{ V}_{\text{AC}}$, output $36.0 \text{ V} @ 5.55 \text{ A (200 W)}$
- Two stages: PFC boost (since $P_{\text{IN}} > 75 \text{ W}$) and isolated DC/DC
- Good transient response, compatible with isolated DC/DC (opto-isolated)
- Good efficiency at light load (1 W to 10 W, typical music listening)
- Low cost

<table>
<thead>
<tr>
<th>Power Capability Target</th>
<th>Continuous</th>
<th>100 W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1 hour (thermal protection)</td>
<td>200 W</td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>400 W</td>
<td></td>
</tr>
<tr>
<td>OC protection (max. 10 ms)</td>
<td>$840 \text{ W} / 22 \text{ A, 8 : 1}$</td>
<td></td>
</tr>
</tbody>
</table>
PFC – Topology Selection

- **Dual-Phase Interleaved TM**
  - UCC28060/61

- **Dual-Phase CCM Interleaved**
  - UCC28070

- **Transition Mode (TM)**
  - UCC28050/51

- **Single-Channel CCM**
  - UCC2817A/18A
  - UCC28019A
  - UCC28180

Complexity and Efficiency

- 80 W to 200 W
- 200 W to 800 W
- 800 W to 1 kW+
PFC – Bandwidth & V-Loop Compensation

• Select \( f_{CO} \leq \frac{2 \cdot f_{min}}{3}, f_{min} = 20\,\text{Hz} \)

• Attenuation @ 100 Hz ≥ 20 dB

• Provide enough \( C_{OUT} \) to avoid triggering of UCC28180 \textit{enhanced dynamic response} (EDR) and to keep PGOOD “on” during transients

• Thanks to low \( f_{CO} \), PFC stage “sees” only RMS output power \( P_{OUT(RMS)} \)

• \( P_{OUT(RMS)} \) will drive FET, magnetics, EMI filter and main diode selection

• 20 Hz sinusoidal audio signal

• Both outputs loaded @ 4 \( \Omega \) (close to clipping)
## Isolated DC/DC – Topology Selection

<table>
<thead>
<tr>
<th>Topology</th>
<th>Power Level</th>
<th>Benefits</th>
<th>Drawbacks</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flyback</td>
<td>&lt;100 W</td>
<td>• Low parts count</td>
<td>• Poor efficiency at high power levels</td>
<td>Lowest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Single magnetic</td>
<td>• High peak currents</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Wide input-voltage range</td>
<td>• High voltage power switch</td>
<td></td>
</tr>
<tr>
<td>Half-bridge</td>
<td>100 W to 500 W</td>
<td>• Power switch stress = $V_{IN}$</td>
<td>• High-side drive</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Coupled inductor</td>
<td>• Volt-second balance of transformer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Max duty-cycle &lt; 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-switch</td>
<td>100 W to 500 W</td>
<td>• Power switch stress = $V_{IN}$</td>
<td>• High-side drive</td>
<td>Moderate</td>
</tr>
<tr>
<td>forward</td>
<td></td>
<td>• Coupled inductor</td>
<td>• 50% duty-cycle limit</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Clamped transformer reset</td>
<td>• Larger inductor value</td>
<td></td>
</tr>
</tbody>
</table>
Isolated DC/DC – $C_{BOOT}$ Recharging

- Simple single-ended CM controller
- Skip-cycle mode improves efficiency at light load
- Challenge $\rightarrow$ $C_{BOOT}$ recharging
• $R_{68} \cdot C_{51} \geq \frac{\pi}{2} \cdot \sqrt{L_M \cdot 2C_{OSS}}$, $L_M = T_1$ mag. inductance, $C_{OSS}(Q_1, Q_2)$

• $Q_{11}$ switches at almost zero voltage (ZVS) at nominal duty-cycle

• $C_{BOOT}$ recharged in all conditions ($V_{IN}$, $V_{OUT}$, load) at expense of $Q_1$ & $Q_2$ SW losses imbalance
Isolated DC/DC – Output Cap. Requirement

- Assumed starting point: \( f_{CO} \sim 5 \text{ kHz}, R_{ESR}(C_{OUT}) \sim 25 \text{ m}\Omega, L_{OUT} = 50 \text{ \( \mu \)H} \)
  
  - To keep \( THD \leq 0.016\% \)
  
  - \( PV_{DD(\text{NOM})} = 36.0 \text{ V} \)

\[
C_{OUT} \geq \frac{1}{2 \cdot \pi \cdot 2\Omega \cdot 5 \text{ kHz}} = 16 \text{ \( \mu \)F}
\]

- \( \Delta V_{\text{OVERSHOOT}} \leq PV_{DD(\text{ABSMAX})} - PV_{DD(\text{NOM})} = 38.0 \text{ V} - 36.0 \text{ V} = 2.0 \text{ V} \)

- \( \Delta V_{\text{UNDERSHOOT}} \leq PV_{DD(\text{NOM})} - PV_{DD(\text{CLIPPING})} = PV_{DD(\text{NOM})} \cdot (1 - D_{MAX}) = 36.0 \text{ V} \cdot (1 - 95\%) = 1.8 \text{ V} \)

\[
C_{OUT} \geq \frac{\Delta I}{8 \cdot f_{CO} \cdot \sqrt{\Delta V_{\text{UNDERSHOOT}}^2 - (R_{ESR} \cdot \Delta I)^2}} = \frac{22.0 \text{ A}}{8 \cdot 5 \text{ kHz} \cdot \sqrt{(1.8 \text{ V})^2 - (10 \text{ m}\Omega \cdot 22 \text{ A})^2}} = 321 \text{ \( \mu \)F}
\]

\[
C_{OUT} \geq \frac{L_{OUT} \cdot \Delta I^2}{(V_{OUT} + \Delta V_{\text{OVERSHOOT}})^2 - V_{OUT}^2} = \frac{50 \text{ \( \mu \)H} \cdot (22.0 \text{ A})^2}{(36.0 \text{ V} + 2.0 \text{ V})^2 - (36.0 \text{ V})^2} = 164 \text{ \( \mu \)F}
\]
Isolated DC/DC – Loop Compensation

- Current mode controller  
  → Select type II compensation
- $Q_4$ provides Class-G $V_{OUT}$ switch
- Over-temperature (OT) pulls down $V_{OUT}$ to 18 V to limit output power
- Compensation network  
  - Zero @ 184 Hz
  - Pole @ 184 kHz (filter)
- 4.5 kHz crossover frequency
- 60 deg phase margin
Isolated DC/DC - Transient Response

Minimum output capacitor: 3 x 100 μF / 74 mΩ electrolytic in parallel with 10 μF ceramic

\[ X_{OUT} \approx \frac{1}{8 \cdot 3 \cdot C_{OUT(SINGLE)} \cdot f_{CO}} = 92.6 \, m\Omega \]

\[ ESR_{C(OUT)} = \frac{ESR_{C(OUT), SINGLE}}{3} = 24.7 \, m\Omega \]

\[ Z_{OUT} = \sqrt{X_{C(OUT)}^2 + ESR_{C(OUT)}^2} = 95.8 \, m\Omega \]

Output voltage variation \( \Delta V \) during load transients \( \Delta I = 10 \, A - 1 \, A \)

\[ \Delta V = \Delta I \cdot Z_{OUT} = 9.0 \, A \cdot 95.8 \, m\Omega = 862 \, mV \]

\[ \Delta V = 2.4\% \]
System Audio Performance: PSU + EVM

- PMP10215 power supply **customized** for highest performance
- Almost no difference in audio performance (THD) between PMP10215 PSU and a reference lab supply
- + 10% efficiency improvement in Class-G mode (supply voltage switch 36 V → 18 V) in range 10 W to 50 W
- Low THD over a wide power range
Part 4
Automotive Power Supply
## Specification

### High-power & high-end car audio amplifier

Customer: “We need 700 W!”

<table>
<thead>
<tr>
<th>TPA3251 #1 in BTL Mode</th>
<th>TPA3251 #2 in PBTL Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left and right channel with full audio bandwidth</td>
<td>Subwoofer with 80 Hz low pass</td>
</tr>
<tr>
<td>2x 175 $W_{RMS}$ / 2x 350 $W_{PEAK}$ into 4 Ω load @ 10% THD</td>
<td>1x 350 $W_{RMS}$ / 1x 700 $W_{PEAK}$ into 2 Ω load @ 10% THD</td>
</tr>
<tr>
<td>2x 120 $W_{RMS}$ / 2x 240 $W_{PEAK}$ into 4 Ω load @ 0.1% THD</td>
<td>1x 240 $W_{RMS}$ / 1x 480 $W_{PEAK}$ into 2 Ω load @ 0.1% THD</td>
</tr>
<tr>
<td>0 dBu (-2.2 dBV) input level for full power (standard for European pro audio)</td>
<td></td>
</tr>
<tr>
<td>2.2 $V_{PEAK-PEAK}$ / 0.775 $V_{RMS}$ @ 600 Ω (1 mW)</td>
<td></td>
</tr>
<tr>
<td>Power source is car battery (9 to 16 V nominal for full load, 6 to 16 V operating)</td>
<td></td>
</tr>
</tbody>
</table>
## Topology Selection

### Serious power specification

<table>
<thead>
<tr>
<th>Topology Specification &amp; Selection</th>
</tr>
</thead>
</table>
| Audio power @ 0.1% THD | 240 $W_{RMS}$ / 480 $W_{PEAK}$ per amplifier  
→ 480 $W_{RMS}$ / 960 $W_{PEAK}$ total |
| Crest factor 1:8 | 120 $W_{RMS}$ continuous |
| Current consumption at 36.0 V supply voltage | Class-D efficiency: 90%, power supply efficiency: 95%  
\[
I_{AVG} = \frac{120 \ W_{RMS}}{0.9 \cdot 0.95 \cdot 36.0 \ V} = 3.9 \ A 
\]
\[
I_{PEAK} = \frac{960 \ W_{PEAK}}{0.9 \cdot 0.95 \cdot 36.0 \ V} = 31.2 \ A 
\]  
Unlikely both amplifiers need maximum peak power at same time  
→ Limit max. current to 20.0 A |
| Topology | Interleaved synchronous boost with 2x LM25122-Q1 as no galvanic isolation is needed and it supports high efficiency over wide load range |

### Diagram

- **Synchronous-Booster**: LM25122-Q1  
- **Class-D Amplifier**: TPA3251D2  
- **Pre-Amplifier**: OPA1662A-Q1  
- **Low-Pass**: OPA1662A-Q1
Component Selection

Capacitors
- Enough input capacitance to stay below input negative impedance of power supply
- Ceramic capacitors on booster output
- Low ESR & high ripple current capacitors for Class-D input

FETs
- Paralleled low-side FETs for heat spread and to enable high peak power capability
- Single high-side sync-FET

Inductors
- Flat wire inductors with ferrite core for highest efficiency
Post Filter

Purpose
• Reduce AC current stress for electrolytic capacitors
• Provide a clean supply voltage for amplifier

Components
• Ceramic capacitors cover large AC currents, but relatively high voltage ripple
• Low pass at approx. 1/10 of switching frequency formed by small inductor and electrolytic capacitors → Theoretically 40 dB ripple rejection
• Damping resistor for post-filter inductor only necessary for high Q filters
Measurements – Boost Power Supply

**Efficiency – 36.0 V up to 10.0 A Load**
- 13.8 V input
- 95.5 % peak efficiency @ 5.0 A load, very flat efficiency curve

**Bode Plot – 36.0 V @ 10.0 A Load**
- 13.8 V input
- 830 Hz bandwidth, 81 deg phase margin, -21 dB gain margin
System Audio Performance

### THD vs. Frequency

| 12.0 V input | 25 W, 50 W, 75 W, 100 W @ 4 Ω load |

- Red: 100 W
- Yellow: 75 W
- Green: 50 W
- Cyan: 25 W

### THD vs. Power

| 12.0 V input | Channel 1 & 2 @ 4 Ω load with 1 kHz |

- Red: Left Channel
- Blue: Right Channel
Photos

PMP10215 - AC/DC Power Supply & TPA3251D2 350 W Class-D Audio EVM
http://www.ti.com/tool/PMP10215
http://www.ti.com/tool/TPA3251D2EVM

PMP11769 - Complete Automotive Audio System
http://www.ti.com/tool/PMP11769
Conclusion

- Texas Instruments Class-D audio amplifiers have ability to deliver clean signals even when supply voltage isn’t that clean
- Minimum output filter capability has been calculated keeping in mind audio performance (THD) degradation
- AC/DC with PFC and automotive solution have been presented
- Test results show for both cases there is almost no difference between reference PSU and our solutions
- Further analysis might include efficiency improvement over different DC/DC topologies (half-bridge vs. 2-SW forward vs. LLC resonant)
References

- UCC28180 Design Calculator
  http://www.ti.com/lit/zip/sluc506

- LM5021 Tools

- LC Filter Design (Class-D Amplifier)

- TPA3251 175 W Stereo / 350 W Mono Ultra-HD, Analog-In Class-D Amplifier
  http://www.ti.com/product/TPA3251

- PMP10215 - AC/DC Power Supply
  http://www.ti.com/tool/PMP10215

- PMP11769 - Automotive Audio System
  http://www.ti.com/tool/PMP11769
Appendix – Thermal Interface

- Spring-pressure setup to ensure a low thermal resistive connection between IC and heat sink
- Thermal foil to equalize minimal height differences as a single heat sink is used for both Class-D ICs, otherwise use heat-conductive paste
- Springs apply constant pressure and reduce mechanical stress compared to solution where heat sink is directly screwed to PCB
- Same setup for cooling booster FETs
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