Minimize Idle Current in Portable Audio With TAS5805M Hybrid Mode

Shawn Zheng, Peter Cao

ABSTRACT
The Class-D audio amplifier is an important piece of the portable audio design, and is confronted with many challenges such as smaller form factors, lower power, and higher performance. To achieve low power losses, multiple factors must be taken into consideration, including the PWM switching frequency, the inductors in the output LC filter, and the modulation mode of the amplifier. This application note explains and compares how each factor affects the idle current using the TAS5805M, which features the ultra-low-idle-current Hybrid Mode Modulation.

Contents
1 General Overview ........................................................................................................... 2
2 Ripple Current on the Inductors .................................................................................... 2
3 LC Filter Configuration .................................................................................................. 3
4 PWM Frequency .............................................................................................................. 4
5 Modulation Mode ........................................................................................................... 4
6 THD Performance Measurement .................................................................................... 6
7 Conclusion ...................................................................................................................... 6

List of Figures
1 PVDD/2 Common-Mode Voltage .................................................................................. 2
2 PWM Voltage Waveform .............................................................................................. 2
3 Inductor Voltage and Current ....................................................................................... 2
4 Idle Current vs PVDD on TAS5805M (F_{sw} = 384 kHz, Hybrid Mode) ....................... 3
5 Idle Current vs PVDD on TAS5805M (F_{sw} = 768 kHz, BD Mode) .......................... 3
6 Idle Current vs PVDD on TAS5805M (10 µH + 0.68 µF LC Filter, BD Mode) .......... 4
7 PWM Voltage Waveform (15% Duty-Cycle) ............................................................... 4
8 Inductor Voltage and Current (15% Duty-Cycle) ......................................................... 4
9 Idle Current vs PVDD on TAS5805M (F_{sw} = 384 kHz, 10 µH + 0.68 µF LC Filter) .......... 5
10 Idle Current vs PVDD on TAS5805M (F_{sw} = 384 kHz, 22 µH + 0.68 µF LC Filter) ...... 5
11 Idle Current vs PVDD on TAS5805M (F_{sw} = 768 kHz, 10 µH + 0.68 µF LC Filter) ...... 5
12 THD vs Input Frequency (PVDD = 12 V, Load = 6 Ω, 10 µH + 0.68 µF, 1-W Output Power) 6
13 THD vs Input Frequency (PVDD = 12 V, Load = 6 Ω, 10 µH + 0.68 µF, 5-W Output Power) 6

List of Tables

Trademarks
All trademarks are the property of their respective owners.
General Overview

The low idle current helps to extend the battery life and reduce the power consumption in consumer electronics. To achieve lower idle current, the TAS5805M supports different LC filter configurations, PWM frequency and modulation mode configurations.

2 Ripple Current on the Inductors

Ripple current on the inductors is defined as the alternating current flowing through the output inductor of a class-D amplifier. The ripple current contributes the most to the total idle current. Lower ripple current on the inductors makes lower idle current. This application report analyzes the ripple current in idle state.

Figure 1 shows that when in BD modulation mode, class-D amplifiers produce a common-mode voltage of PVDD/2 after the LC filter at idle, which is the average value of the 50% duty-cycle PWM switching waveform.

![Figure 1. PVDD/2 Common-Mode Voltage](image)

Therefore, the voltage across the output inductor changes the polarity when the PWM voltage reaches PVDD/2. The maximum voltage across the inductor is PVDD/2 and the minimum voltage is –PVDD/2 (see Figure 2).

![Figure 2. PWM Voltage Waveform](image)

Figure 3 shows the inductor voltage and current waveforms drawn using these arguments.

![Figure 3. Inductor Voltage and Current](image)
At idle, the positive and negative current flow through the inductor must be symmetrical and therefore centered around zero. Otherwise, there is a DC offset across the speaker and a constant average current flow through the load. The shaded regions in Figure 3 indicate the direction of current flow.

Calculate the peak ripple current at idle with Equation 2:

\[
I_{\text{ripple,peak}} = \frac{PVDD}{L} \times \frac{1}{4 \times F_{SW}}
\]

\[
I_{\text{ripple,peak}} = \frac{PVDD}{2 \times L} \times \frac{1}{8 \times F_{SW}}
\]

where

- \( L \) = inductor value
- \( F_{SW} \) = PWM switching frequency

3 LC Filter Configuration

Equation 2 shows that the larger value inductors in the output filter make lower ripple current in idle state. Figure 4 shows the idle current with three different LC filter configurations (22 \( \mu \)H, 15 \( \mu \)H, and 10 \( \mu \)H) for \( F_{SW} = 384 \text{ kHz} \) and Hybrid mode. Figure 5 shows the idle current with 4.7-\( \mu \)H and 10-\( \mu \)H inductors for \( F_{SW} = 768 \text{ kHz} \) and BD mode.

![Figure 4. Idle Current vs PVDD on TAS5805M (F_{SW} = 384 kHz, Hybrid Mode)](image)

![Figure 5. Idle Current vs PVDD on TAS5805M (F_{SW} = 768 kHz, BD Mode)](image)
4 PWM Frequency

Equation 2 shows that the idle current is lower with higher PWM frequency. Figure 6 shows the idle current measurement for \( F_{SW} = 384 \text{ kHz} \) and 768 kHz (10-μH inductor and BD mode).

Figure 6. Idle Current vs PVDD on TAS5805M (10 μH + 0.68 μF LC Filter, BD Mode)

5 Modulation Mode

The TAS5805M device supports BD mode, 1SPW mode, and Hybrid mode. The duty-cycle is lower in 1SPW mode and Hybrid mode than it is in BD mode.

Using 15% duty-cycle as an example, the common-mode voltage after the LC filter is 0.15 × PVDD, as Figure 7 shows. The maximum voltage across the inductor is 0.85 × PVDD and the minimum voltage is −0.15 × PVDD, as Figure 8 shows.

Figure 7. PWM Voltage Waveform (15% Duty-Cycle)

Figure 8. Inductor Voltage and Current (15% Duty-Cycle)

Apparently, the idle current is lower with the lower duty-cycle (< 50%). Figure 9, Figure 10, and Figure 11 compare the idle current between BD mode, 1SPW mode, and Hybrid mode, under different PWM switching frequencies and LC filter configurations.
Figure 9. Idle Current vs PVDD on TAS5805M ($F_{SW} = 384$ kHz, $10 \mu H + 0.68 \mu F$ LC Filter)

Figure 10. Idle Current vs PVDD on TAS5805M ($F_{SW} = 384$ kHz, $22 \mu H + 0.68 \mu F$ LC Filter)

Figure 11. Idle Current vs PVDD on TAS5805M ($F_{SW} = 768$ kHz, $10 \mu H + 0.68 \mu F$ LC Filter)
6  THD Performance Measurement

THD performance is measured for 1- and 5-W output power with 12-V PVDD, 6-Ω load, and a 10-µH inductor, as Figure 12 and Figure 13 show.

The THD performance in Hybrid mode is close to BD mode. While in 1SPW mode, the THD performance is slightly worse than BD mode or Hybrid mode. The blue (cyan) curve is for 1-W output power in 1SPW mode, the green curve is for 1-W output power in BD mode, and the red one is 1 W in Hybrid mode.

![Figure 12. THD vs Input Frequency (PVDD = 12 V, Load = 6 Ω, 10 µH + 0.68 µF, 1-W Output Power)](image1)

![Figure 13. THD vs Input Frequency (PVDD = 12 V, Load = 6 Ω, 10 µH + 0.68 µF, 5-W Output Power)](image2)

7  Conclusion

The ripple current on the inductor depends on the output filter configuration, PWM switching frequency, and modulation mode. Very low idle current can be achieved with the TASS805M Hybrid Mode, while maintaining excellent THD performance.
IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated (‘TI’) technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, “TI Resources”) are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI’s provision of TI Resources does not expand or otherwise alter TI’s applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT. AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED “AS IS” AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RelATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include: without limitation, TI’s standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2018, Texas Instruments Incorporated