Application Note

TAS2781 and TAS2783 Hybrid-Pro Boost Controller

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ABSTRACT

The TAS2781 and TAS2783 devices are mono, digital input class-D audio amplifiers optimized for efficiently driving high peak power into small loudspeakers with integrated voltage and current sense. An on-chip digital-signal processor (DSP) supports Texas Instruments' SmartAmp speaker protection algorithm. The TAS2781 operates using time division multiplex (TDM), I^2S, and I^2C (or serial peripheral interface (SPI)) interfaces. The TAS2783 provides a flexible SoundWire 1.2 compatible peripheral interface for control and data, an I^2C peripheral interface, and an I^2S interface for digital audio data communication. The TAS2781 and TAS2783 have an extensive set of features that include the following:

- Integrated DSP for audio processing
- 23-V supply for class-D output stage
- Y-bridge multilevel supply architecture
- Hybrid-Pro external boost control algorithm
- Ultrasonic output support up to 40 kHz

This document provides guidelines for using the Hybrid-Pro feature in the TAS2781 and TAS2783 by giving an overview of the internal algorithm, external interface architecture, PurePath™ Console 3 (PPC3) software, and performance results. The high-efficiency class-D operation with Hybrid-Pro provides approximately 50% longer battery life, essential for portable speaker applications, compared to fixed-supply voltage designs.

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1 Introduction

Traditional audio amplifier systems consist of an audio amplifier and a boost converter with a constant output voltage to achieve the maximum power to be delivered to the speaker load.

Modern audio amplifiers with class-D architecture provide efficiencies higher than 90%. Higher efficiency results in lower power consumption and longer battery-life. This allows class-D amplifiers to be used for compact system designs across various applications like home theater, portable speaker, soundbar, car-audio, and so forth.

The dynamic nature of music, typically, needs maximum voltage for short moments, and only when the listener sets the system to maximum volume. Hence a fixed-voltage power supply is inefficient in most use cases due to larger inductors, MOSFETs, and copper area on the PCB to handle the increased thermal load. These system challenges can be solved with an envelope-tracking power-supply system. The audio signal is analyzed to determine the optimum power supply voltage for a given audio input. The power-supply voltage is adjusted by dynamically controlling the output voltage of the boost converter. The entire system operates to directly match the needs of the audio signal at all times instead of only maintaining the voltage required at the maximum power use-case. Power losses in the system are reduced and power efficiency and thermals improve significantly.

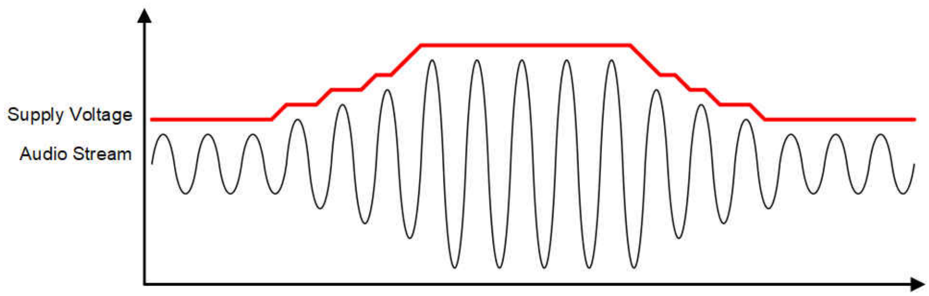


Figure 1-1. Envelope Tracking

In a class-G system, the supply voltage for the class–D output is boosted when needed. The audio amplifier is able to monitor the input audio stream and determine the corresponding optimum output voltage for the amplifier. If the output voltage exceeds a certain threshold then the boost is enabled to provide additional headroom. In class-H amplifiers, the output voltage level of the boost converter for the amplifier has a more granular level. With this implementation there can be several possible supply voltages as shown in Figure 1-3. This enables the output to operate with just enough headroom to maintain low distortion while achieving higher output efficiency.

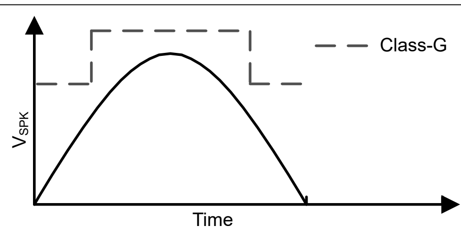


Figure 1-2. Class-G Profile

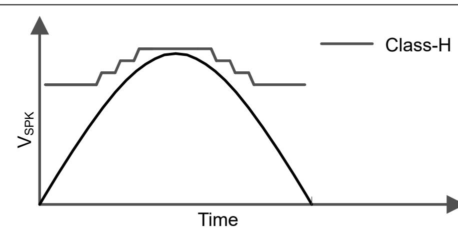


Figure 1-3. Class-H Profile

The integrated class-H controller, usually known as the Hybrid-Pro boost controller, of the TAS2781 and TAS2783 can track the envelope of the incoming audio stream and control the boost converter to adjust the power supply voltage for the audio amplifier. This envelope tracking algorithm looks ahead into the audio signal to detect a peak and prepare the boost converter to switch to a higher supply voltage. The Hybrid-Pro boost controller sends out a pulse-width modulation (PWM) signal, with duty cycle proportional to the peak, to the boost converter. The output from the audio amplifier has a programmable delay to allow the boost converter to settle to the voltage level. When the audio signal starts falling, the tracker holds the peak for a certain duration to prevent rapid voltage fluctuations. Finally, the Hybrid-Pro boost controller follows the falling audio signal using a decay envelope to enable the boost converter to switch to a lower headroom. Monitoring of the audio signal or external control of the boost converter from a microcontroller is not necessary.

2 Hybrid-Pro Boost Controller

The TAS2781 and TAS2783 (hereafter termed TAS278x when interchangeable in this application note) have an internal Hybrid-Pro algorithm allowing users to optimize the efficiency in the system by controlling the external power supply with just enough margin to provide high dynamic range with low distortion.

Features of Hybrid-Pro control:

- Hybrid-Pro control waveform is configurable as either 8 or 16 output voltage steps with 384-kHz or 192-kHz PWM, respectively, for external boost converter
- Configurable maximum 4-ms look-ahead audio signal delay for various bandwidth and load capacitance combinations of external boost converters in the system
- Low distortion output with optimum programmable peak hold time up to 8 ms
- Balances efficiency with envelope tracking by dynamically adjusting the audio signal trigger level and the output voltage step size of the external boost converter

The Hybrid-Pro boost controller generates a PWM signal at the PWM_CTRL pin with a duty cycle proportional to the peak voltage at the speaker. The signal is converted to an analog voltage to control boost converter feedback (FB) input using an external low-pass filter as shown in Figure 2-1 (see Section 3.1 for details).

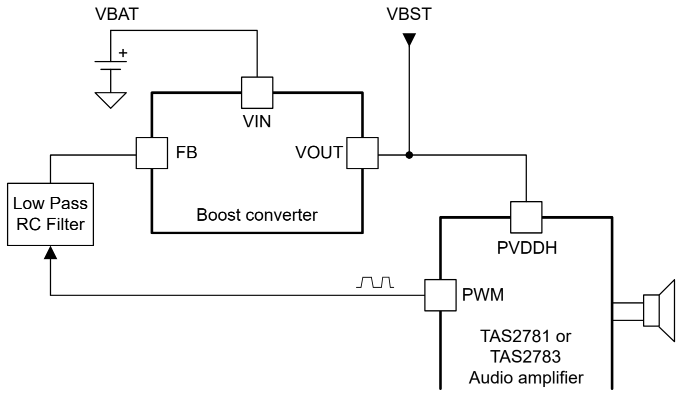


Figure 2-1. TAS2781 or TAS2783 Device Interface With Boost

By default, the PWM_CTRL pin is configured in an open drain. This configuration allows an easy implementation of a multichannel control loop using a common low-pass filter (LPF). Multiple TAS278x devices can be connected to the same LPF. One pullup resistor is needed between the common connection of the pins and IOVDD rail (see Figure 2-2).

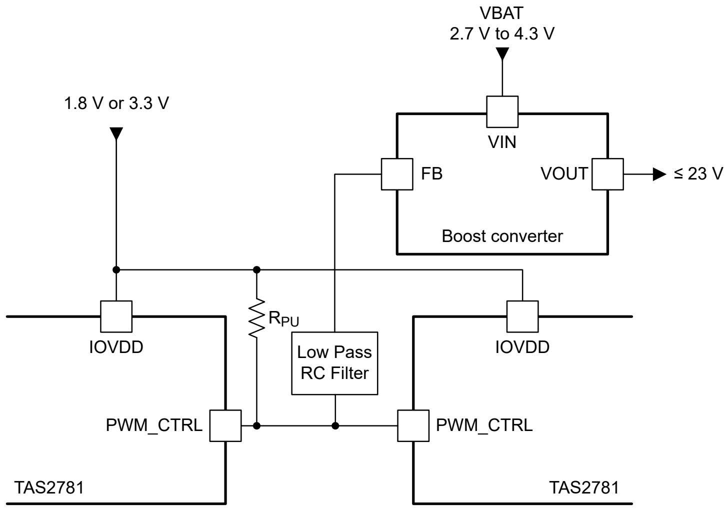


Figure 2-2. Multichannel Configuration Using PWM_CTRL Pin With Open Drain

When only one amplifier is driving the LPF, program the PWM_CTRL pin as a push-pull driver. This helps to improve efficiency and reduce one of the external components.

3 Hardware, Software, and Test Results

The Hybrid-Pro boost-controller tests are performed using the hardware and software in the following list:

- Hardware – TAS278x Evaluation Module
- Software – PurePath™ Console - TAS278x EVM

3.1 Hardware Connections

3.1.1 Schematic Connections

The connections for the Hybrid-Pro PWM output (PWM_CTRL pin) of the TAS278x and the FB pin of the boost converter are shown in Figure 3-1. The boost converter chosen for the TAS278x EVM is TPS61089. The passive 2nd order low-pass filter converts the PWM signal from the audio amplifier into a DC voltage at the FB pin of the boost converter to control the boost output.

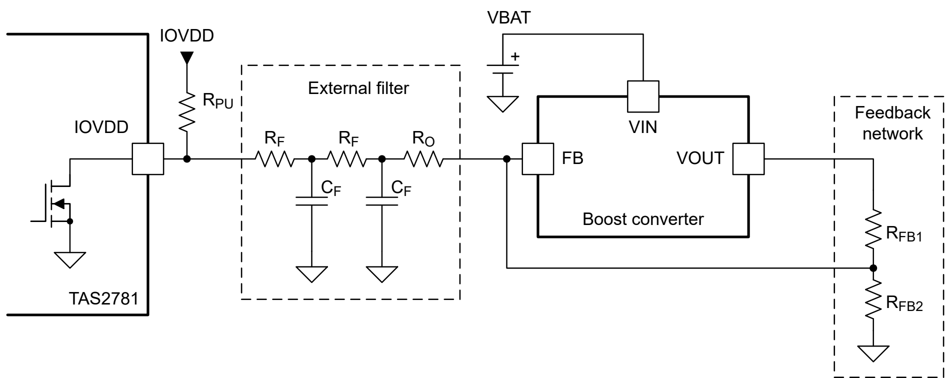


Figure 3-1. Hardware Connections

3.1.2 Equations

Equation 1 and Equation 2 are derived assuming R_O = 0 and PWM_CTRL voltage = 0 V (for duty cycle of 0%) or IOVDD (for duty cycle of 100%):

$$VBST_M = V_{FB} \times \left(1 + \frac{R_{FB1}}{2 \times R_F + R_{PU}} + \frac{R_{FB1}}{R_{FB2}}\right) \tag{1}$$

$$VBST_m = V_{FB} \times \left(1 + \frac{R_{FB1}}{2 \times R_F + R_{PU}} + \frac{R_{FB1}}{R_{FB2}}\right) - IOVDD \times \frac{R_{FB1}}{2 \times R_F + R_{PU}} \tag{2}$$

where

- IOVDD = Supply voltage of the digital interface of TAS278x
- V_{FB} = FB voltage of the boost converter (from boost converter data sheet)
- $VBST_M$ = Maximum output voltage of boost for duty cycle= 0%
- $VBST_m$ = Minimum output voltage of boost for duty cycle = 100%
- R_{PU} = External pullup resistor on PWM_CTRL pin to interface supply of TAS278x

For push-pull configuration of the PWM_CTRL pin, Equation 1 and Equation 2 are derived assuming R_{PU} = 0.

With IOVDD, V_{FB}, $VBST_M$, $VBST_m$ derived from system requirements and resistor R_{FB1} selected (10 kΩ to 1000 kΩ), resistors R_{FB2} and R_F result from solving Equation 1 and Equation 2.

With R_F calculated as previously shown, the cutoff frequency f_C of the low-pass filter can be selected as a few decades lower than the PWM frequency. The capacitor C_F in the low-pass filter can be calculated using Equation 3:

$$C_F \geq \frac{1}{2 \times \pi \times f_C + R_F} \quad (3)$$

On the TAS278x EVM, the TPS61089 boost FB pin is connected to the TAS278x PWM_CTRL pin by installing jumper J14. The FB voltage of the TPS61089 boost converter is 1.212 V and R_{FB1} is chosen as 330 kΩ. Resistors R_{FB2} and R_F are calculated using Equation 1 and Equation 2 for 1.8-V IOVDD operation, such that minimum and maximum boost output voltages are 4.5 V and 12.6 V, respectively. This is the default setting on the TAS278x EVM.

3.2 Software Settings

This section describes the settings for the class-H controller for target applications with the TAS278x EVM and PPC3 GUI.

3.2.1 Steps To Enable Class-H Using PPC3

1. The hardware connections are described in Section 3.1. The TAS278x EVM is powered up using the USB and input power supply. Install the J14 jumper.
2. Launch *TAS278x PPC3* and select the *TAS278x EVM* plug-in.
3. Select the speaker configuration - select either *Mono* or *Stereo* in the speaker configuration window depending on the system requirements.
4. Click the *Start* button at the top-right corner of the GUI window followed by selecting the *Connect* button at the lower-left corner of the GUI window.
5. Navigate to the *Tuning and Audio Processing* page and select a *Tuning Mode*.
6. Enable class-H control in the *Device Control* section. Figure 3-2 and Figure 3-3 show the configurable settings available in this section. Click the *Apply* button to update the device registers.
7. The TAS278x device is ready to play audio stream through USB.

3.2.2 Class-H Configuration Settings

The *Configuration Window* in Figure 3-2 provides the following options:

1. TAS278x Class-H Controls
    - IOVDD Voltage: Default = 1.8 V
    - Hybrid-Pro Feedback (HPFB) PWM steps

Table 3-1. HPFB PWM Steps Configuration

Options	Description	Comments
16 steps	0 V to IOVDD voltage divided into 16 steps with 192-kHz control frequency	Provides smoother control signal at the FB pin of boost converter
8 steps	0 V to IOVDD voltage divided into 8 steps with 384-kHz control frequency	Requires higher cutoff frequency for the external LPF than that used for 16 steps, 192-kHz setting

    - Open-Drain or Push-Pull: The PWR_CTRL pin can be configured in either open-drain or push-pull output. When two devices drive the same external resistive network of the boost converter, the open-drain output is needed. Push-pull gives better efficiency but can be used only with one device associated with a boost converter. When only one TAS278x device is controlling the boost converter, select the push-pull output by deselecting the open-drain checkbox. Check the *Open-drain* box to interface multiple TAS278x devices to the boost converter.

2. Boost Converter Configuration

Table 3-2 shows the configuration options for the boost converter.

Table 3-2. Boost Converter Options

Option	Description
Min Voltage	Expected boost minimum output voltage
Max Voltage	Expected boost maximum output voltage
FB Reference Voltage	FB reference voltage of the boost converter, which is normally listed in the data sheet
R1 Resistance	Boost FB pullup resistor value, used to calculate the pulldown resistor on the FB pin (*R2*) as well as the LPF (*R3*, *C1*, *R4*, *C2*) (refer to Figure 3-2)
Boost Interface Overview	This section shows the hardware circuit connections between TAS278x and boost converter as the recommended circuit for the Hybrid-Pro control application design. The section includes second-order LPF and matching resistor values. These values are calculated based on inputs provided in the configuration window.
TAS278x Output Voltage versus Boost Voltage	PPC3 suite plots the audio output amplitude versus boost output voltage for the TAS278x and boost system settings.

3. Envelope Tracking Algorithm

Figure 3-3 shows the advanced Hybrid-Pro controls. These controls, available for the envelope tracking algorithm, are described in Table 3-3.

Table 3-3. Envelope Tracking

Option	Description
Lookahead Time	TAS278x has maximum 4-ms delay buffer that can be configured based on response of various boost converters for low-distortion
Margin	Class-H margin can be used to add output margin for low distortion by internally fine tuning the threshold and steps. The trade-off is that higher margin results in lower battery life.
Class-H Threshold and Step-Size	PPC3 automatically calculates the class-H threshold and step size based on the system configuration
Inflation Factor	This control is used to artificially inflate the input to correct for any mismatch between the envelope tracking estimate and the class-D output
Peak Hold Time	When the audio signal starts falling, the tracker holds the peak for a certain duration to prevent rapid voltage fluctuations. This needs to be larger than the lookahead time. The default setting is 8 ms.
Smooth	This is the alpha coefficient for the smoothing filter on the audio envelope. The default setting is 24 samples or 0.5 ms at 48 kSPS.
Peak Decay	The class-H controller peak voltage follows the falling audio signal using a decay envelope to enable the boost converter to switch to a lower headroom. The default peak decay is set at –0.4455 dB per sample.

Disable the supply tracking limiter of TAS278x or program the thresholds to a value higher than the maximum output voltage of the boost converter when using the external boost controller.

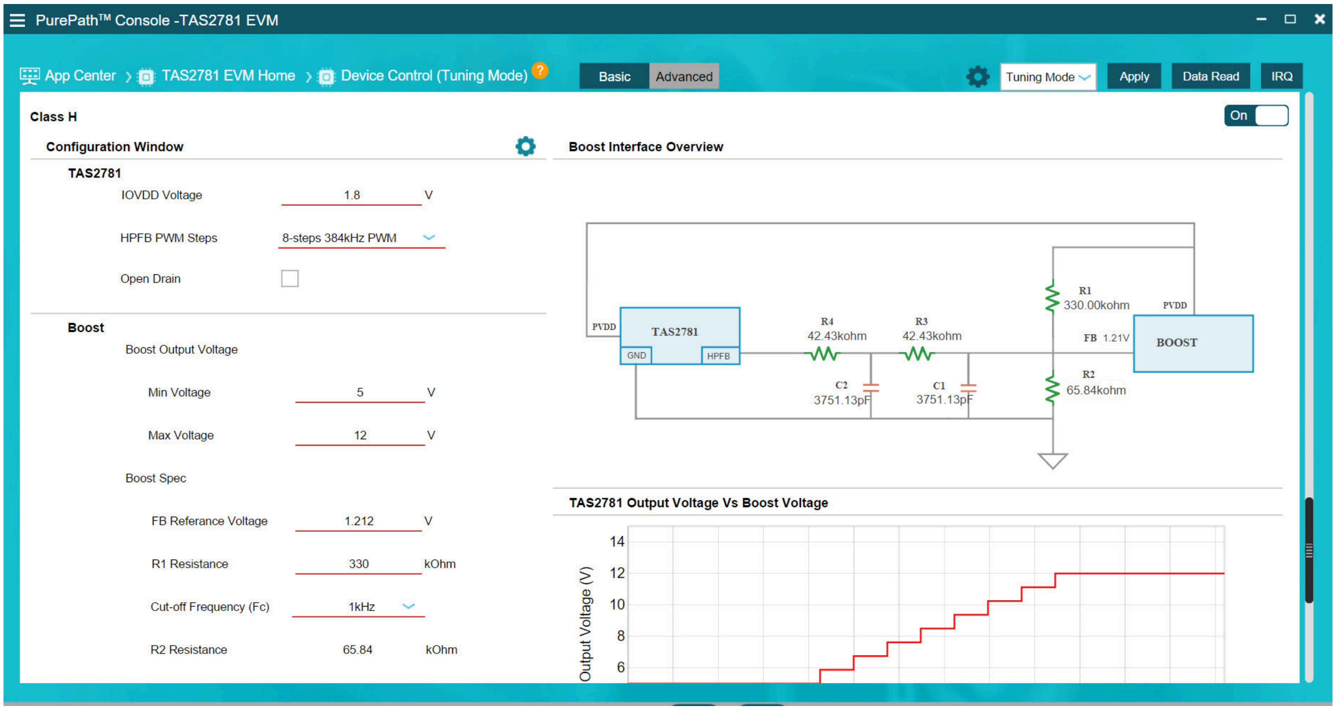


Figure 3-2. Class-H Controls in Device Control Page

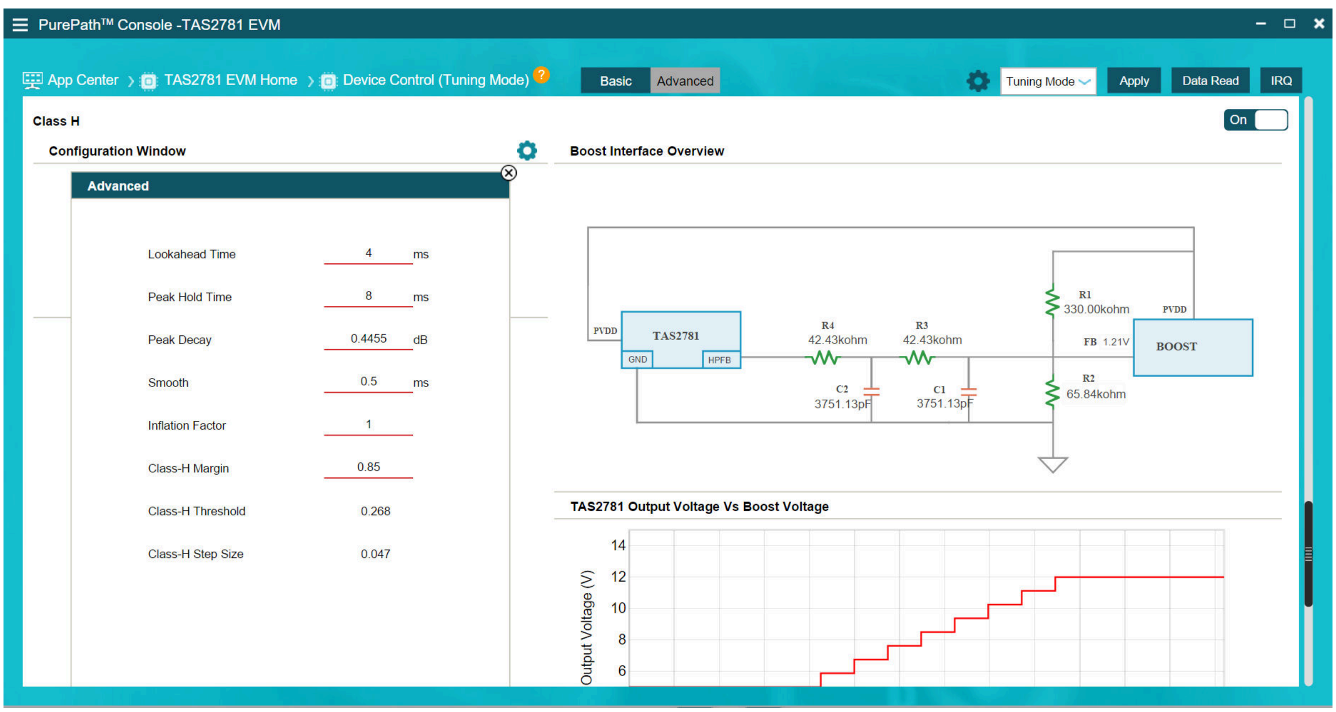


Figure 3-3. Class-H Advanced Controls

Refer to the *PAGE 0x05* and *PAGE 0x06* registers from the register map of the TAS278x data sheet for details on programming the internal class-H controller.

3.3 Hybrid-Pro Feature Performance Results

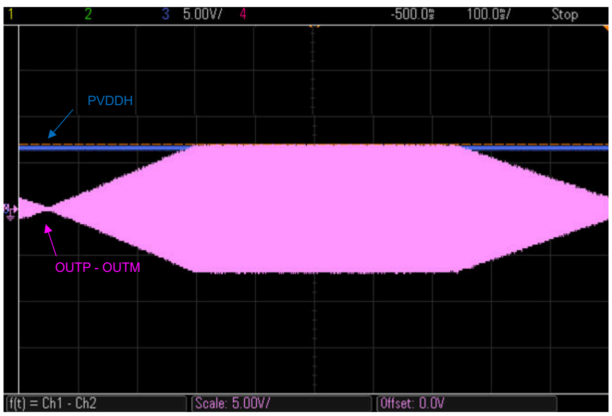
3.3.1 Class-H Operation

The output of the boost converter (PVDDH rail of TAS278x) with and without class-H operation is shown in Figure 3-6 through Figure 3-6. The output of the boost converter is set to a constant voltage when the class-H operation is disabled by disconnecting jumper J14 on the TAS278x EVM. The output voltage of the boost converter follows the envelope of the audio waveform when the class-H operation is enabled.

For all the following test waveforms, the hardware setup is TAS2781 EVM using PPC3, AVDD = IOVDD = 1.8 V, load = 8 Ω + 15 µH, PVDDL = 5 V, boost input = 4.2 V. The following waveforms show the differential output of the TAS278x (OUTP – OUTM) and the PVDDH.

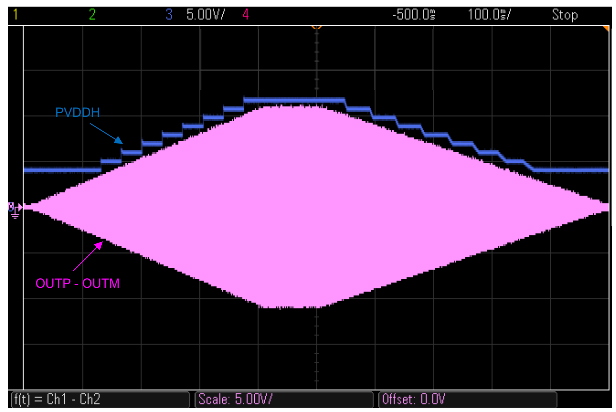
3.3.1.1 PWM Steps

Using Hybrid-Pro Feedback, the PWM waveform format can be configured as 16 steps, 192-kHz PWM or 8 steps, 384-kHz PWM. Here, the audio input is a 1-kHz faded-in and faded-out burst sine wave.



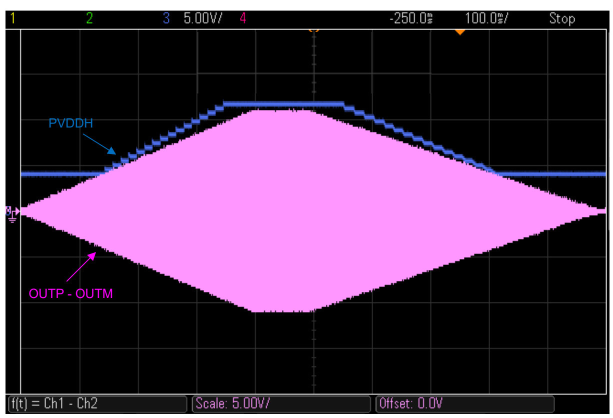
Without Class-H Operation

Figure 3-4. Audio Output and Boost Voltage



With Class-H Operation PWM: 8 Steps, 384 kHz

Figure 3-5. Audio Output and Boost Voltage

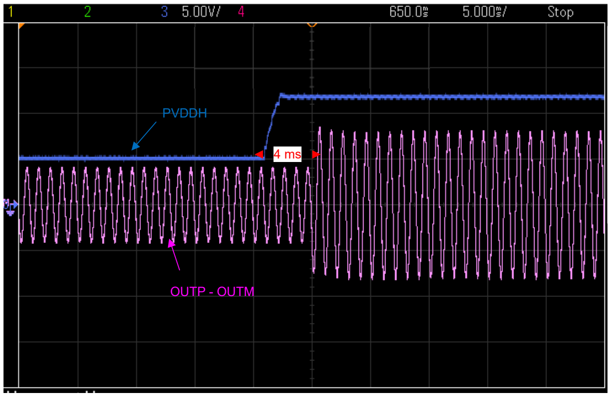


With Class-H Operation PWM: 16 Steps, 192 kHz

Figure 3-6. Audio Output and Boost Voltage

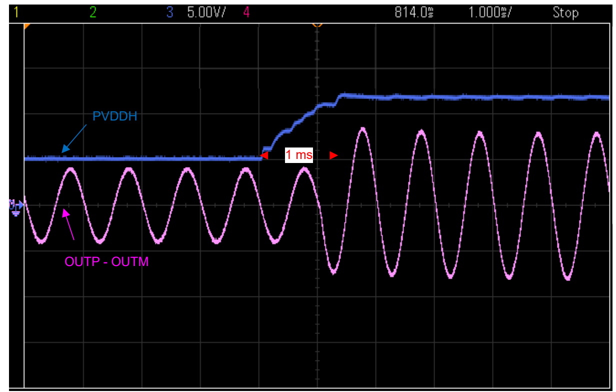
3.3.1.2 Lookahead Time

TAS278x has a maximum 4-ms delay buffer (default), which can be configured based on the response of various boost converters to avoid clipping and distortion. The audio input is a 1-kHz faded-out burst sine wave.



4 ms

Figure 3-7. Lookahead Time

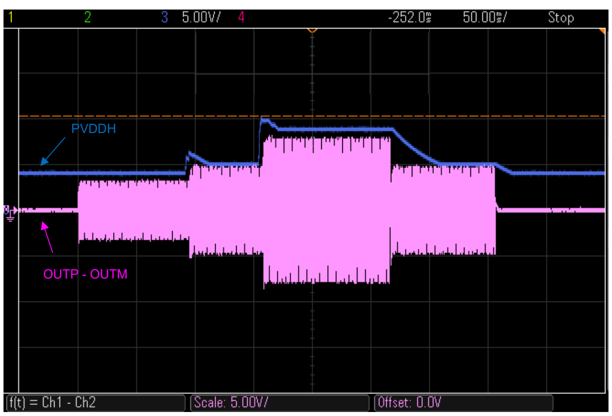


1 ms

Figure 3-8. Lookahead Time

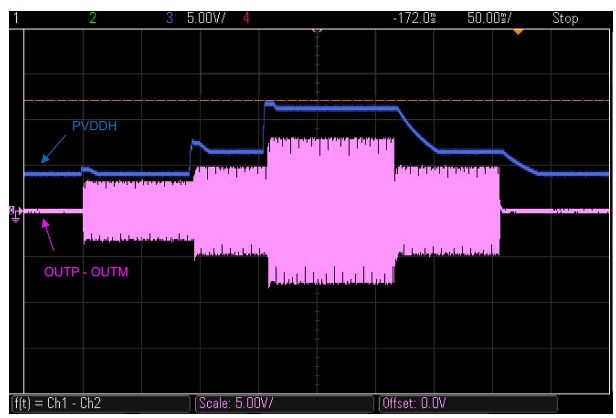
3.3.1.3 Margin

Margin can be used to add output margin to avoid audio clipping. Figure 3-9 and Figure 3-10 show the margin for the 0.85 and 0.7 setting, respectively. A margin of 0.7 provides higher headroom than a margin of 0.85, with a tradeoff with lower efficiency.



Margin of 0.85

Figure 3-9. Output Voltage Margin During PVDDH Transition



Margin of 0.7

Figure 3-10. Output Voltage Margin During PVDDH Transition

3.3.1.4 Inflation Factor

Inflation factor is used to artificially inflate the input to correct for any mismatch between the envelope tracking estimate and the class-D output.

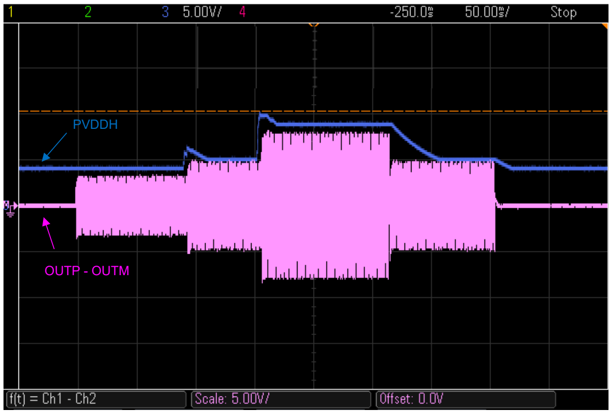


Figure 3-11. Inflation Factor of 1

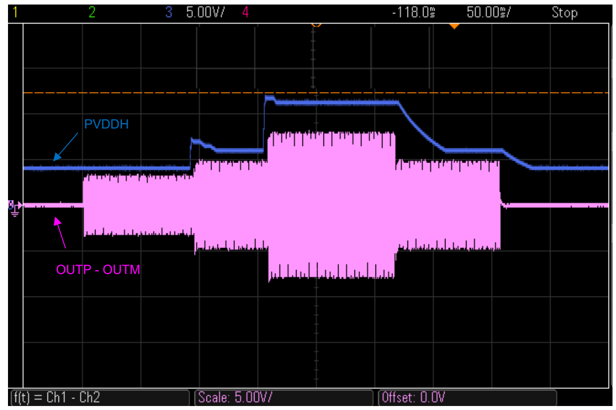


Figure 3-12. Inflation Factor of 1.2

3.3.2 Battery Life

Figure 3-13 shows the battery life measured using a system comprised of the TAS2781 audio amplifier and the TPS61089 boost converter. The boost input is powered using a battery and boost output powers the PVDDH rail of the TAS2781 such that the voltage can vary between 5 V to 12 V. For this test, a music track is played on a loop and the battery voltage is recorded. Battery life is measured for class-H and class-G operation in PWR_MODE0 of the TAS2781 (Y-Bridge is disabled). In absence of an external boost controller, the Y-Bridge algorithm can be used to improve efficiency and battery life. Refer to the *Power Supply Modes* section of the TAS278x data sheet for details. In class-H as well as class-G, the PVDDH supply of TAS278x tracks the audio stream. In the use case of no control operation, the TAS278x operates on constant PVDDH supply.

Table 3-4. Battery Life Test Conditions

Test Condition	Description
Battery	4.5 V, 1500 mAh fully-charged (common AA batteries in 3S configuration)
AVDD and IOVDD Power Supply	1.8 V
PVDDL Power Supply	5 V
Power Supply Mode	PWR_MODE0 Refer to the *Power Supply Modes* section of TAS278x data sheet for details
Speaker Load	8 Ω + 15 µH
Music Track	Famous Artist- Popular Song

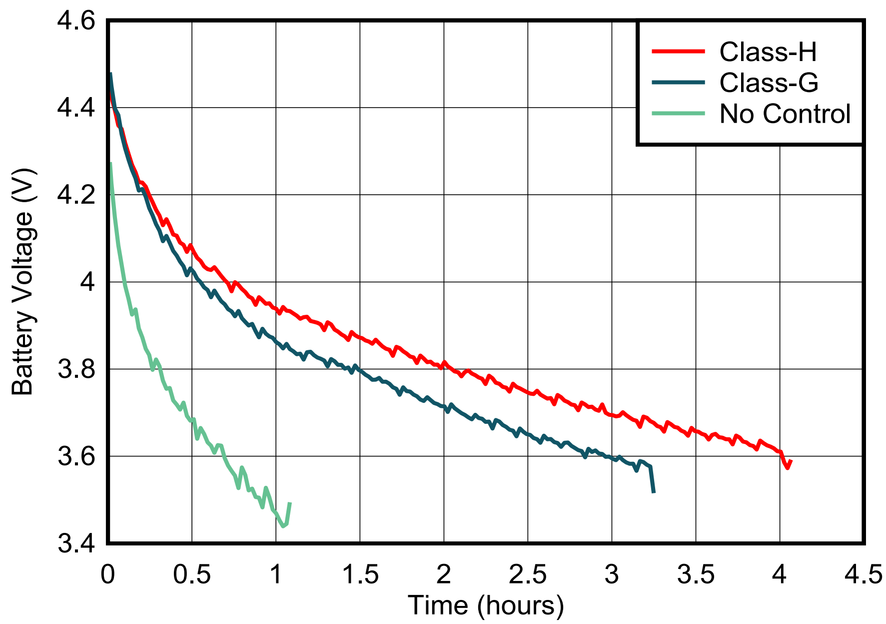


Figure 3-13. Battery Life: Class-H, Class-G, and No Control

3.3.3 Thermal Performance

Figure 3-14 through Figure 3-17 are thermal images that demonstrate the improvement in efficiency of the system when running the system with class-H. The test setup was performed with an 1-kHz sine wave varying between zero and full power faded-in and faded-out repeatedly. The system was allowed to reach a stable temperature before capturing the images with a thermal camera.

Class-H operation improves system efficiency by significantly reducing thermal losses.

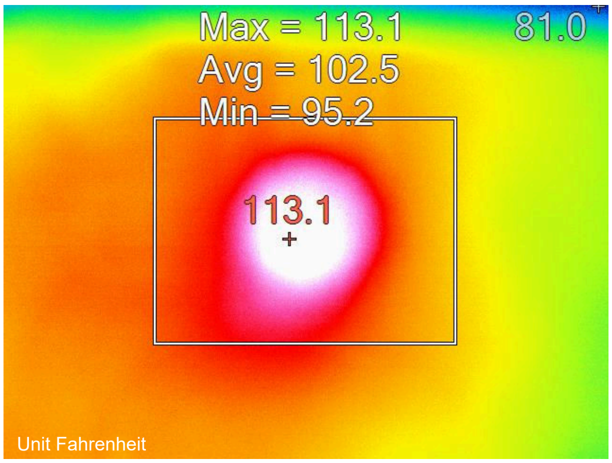


Figure 3-14. Boost With Class-H Disabled

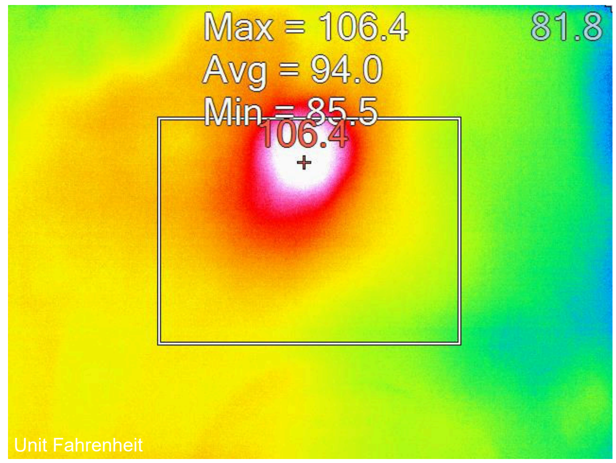


Figure 3-15. Boost With Class-H Enabled

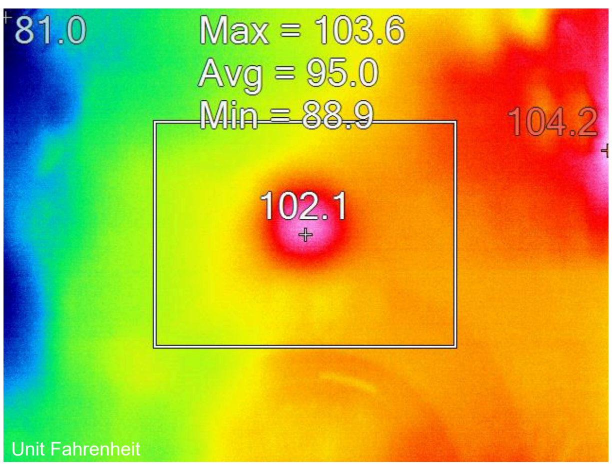


Figure 3-16. Amplifier With Class-H Disabled

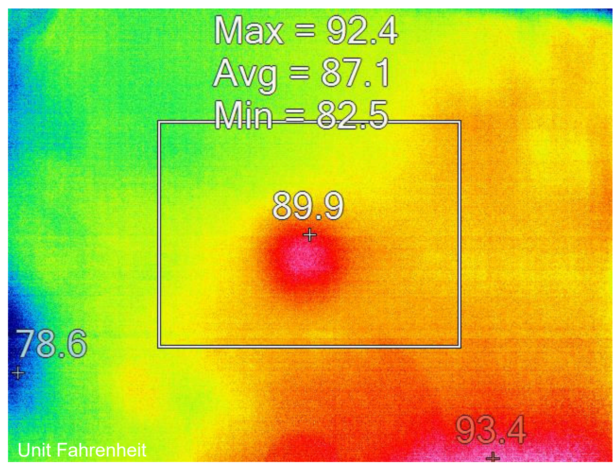


Figure 3-17. Amplifier With Class-H Enabled

4 References

1. Texas Instruments, *TAS2781 23-V Class D Amplifier with Real Time Integrated Speaker Protection and Audio Processing* data sheet
2. Texas Instruments, TAS2783 23-V SoundWire Class-D Amplifier with Real Time Integrated Speaker Protection and Audio Processing data sheet
3. Texas Instruments, *TPS61089x 12.6-V, 7-A Fully-Integrated Synchronous Boost Converters in 2.0-mm x 2.5-mm VQFN Package* data sheet
4. Texas Instruments, *Benefits of Class-G and Class-H Boost in Audio Amplifiers* application note
5. Texas Instruments, *TIDA-020033 Automotive Class-H Audio and Tracking Power Supply* reference design

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