Texas Instruments

TPA005D02 Class D Stereo Audio Power Amplifier Evaluation Module

User’s Guide

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Mixed-Signal Products

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Preface

Related Documentation From Texas Instruments

- ***TI Plug-N-Play Audio Amplifier Evaluation Platform*** (literature number SLOU011) provides detailed information on the evaluation platform and its use with TI audio evaluation modules.

- ***TPA005D02 CLASS D STEREO AUDIO POWER AMPLIFIER*** (literature number SLOS227) This is the data sheet for the TPA005D02 audio amplifier integrated circuit.

FCC Warning

This equipment is intended for use in a laboratory test environment only. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to subpart J of part 15 of FCC rules, which are designed to provide reasonable protection against radio frequency interference. Operation of this equipment in other environments may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.

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Chapter 1

Introduction

This chapter provides an overview of the Texas Instruments (TI™) TPA005D02 Class D Stereo Audio Amplifier Evaluation Module (SLOP223). It includes a list of EVM features, a brief description of the module illustrated with a pictorial diagram, and a list of EVM specifications.

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1.1 Feature Highlights

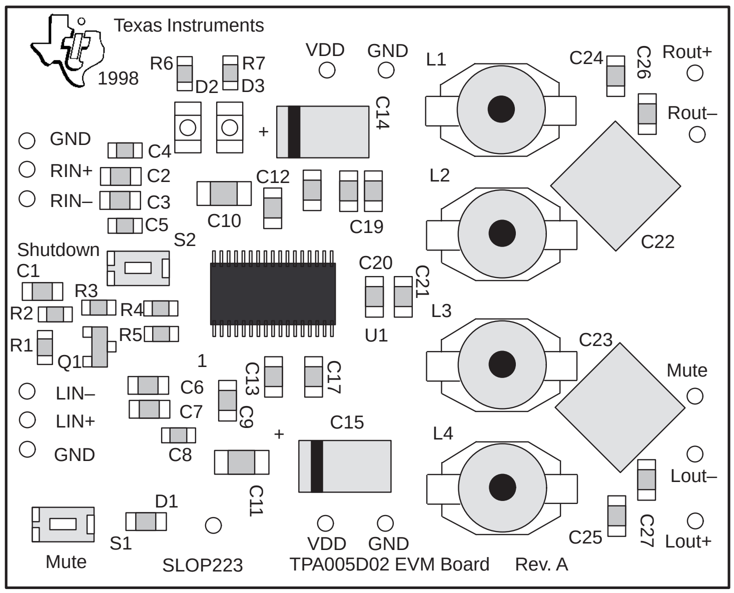
The TI TPA005D02 Class D Stereo Audio Amplifier Evaluation Module and the TI Plug-N-Play Audio Amplifier Evaluation Platform include the following features:

- TPA005D02 Class D Stereo Audio Power Amplifier Evaluation Module
  - External depop circuitry to eliminate turn-on transients in outputs
  - Dual channel, bridge-tied load (BTL) only operation
  - 5-V operation
  - 2 W per channel output power into 4 Ω at 5 V, BTL
  - Low current consumption in shutdown/mute mode (400 μA)
  - Module gain set to 24 dB
  - High efficiency
- Quick and Easy Configuration with The TI Plug-N-Play Audio Amplifier Evaluation Platform
  - Evaluation module is designed to simply plug into the platform, automatically making all signal, control, and power connections
  - Platform provides flexible power options
  - Jumpers on the platform select power and module control options
  - Switches on the platform route signals
  - Platform provides quick and easy audio input and output connections
- Platform Power Options
  - External 5-V – 15-V DC V_{CC} supply inputs
  - External regulated V_{DD} supply input
  - Socket for onboard 5 V/3.3 V V_{DD} voltage regulator EVM
  - Onboard overvoltage and reverse polarity power protection
- Platform Audio Input and Output Connections
  - Left and right RCA phono jack inputs
  - Miniature stereo phone jack input
  - Left and right RCA phono jack outputs
  - Left and right compression speaker terminal outputs
  - Miniature stereo headphone jack output

1.2 Description

The TPA005D02 Class D Stereo Audio Power Amplifier Evaluation Module is a complete, 2-Watt per channel stereo audio power amplifier. It consists of the TI TPA005D02 Class D Stereo Audio Power Amplifier IC along with a small number of other parts mounted on a circuit board that measures approximately 2 1/4 inches by 1 3/4 inches (Figure 1–1).

Figure 1–1. The TI TPA005D02 Class D Stereo Audio Amplifier Evaluation Module



Single in-line header pins extend from the underside of the module circuit board to allow the EVM to either be plugged into the TI Plug-N-Play Audio Amplifier Evaluation Platform, or to be wired directly into existing circuits and equipment when used stand-alone.

The platform has room for a single TPA005D02 class D evaluation module and is a convenient vehicle for demonstrating TI’s audio power amplifier and related evaluation modules. The EVMs simply plug into the platform, which automatically provides power to the modules, interconnects them correctly, and connects them to a versatile array of standard audio input and output jacks and connectors. Easy-to-use configuration controls allow the platform and EVMs to quickly model many possible end-equipment configurations.

There is nothing to build, nothing to solder, and nothing but the speakers included with the platform to hook up.

1.3 TPA005D02 Class D EVM Specifications

Supply voltage range, V_{DD} . . . . 4.5 V to 5.5 V
Supply current, I_{DD} . . . . 2.8 A max
Continuous output power per channel, P_O: 4-Ω BTL, V_{DD} = 5 V . . . . 2 W
Audio input voltage, V_I: . . . . 0.47 Vpp max
Load impedance, R_L . . . . 4 Ω

Chapter 2

Quick Start

Follow the steps in this chapter to quickly prepare the TPA005D02 Class D Stereo Audio Amplifier EVM for use. Using the TPA005D02 class D EVM with the TI Plug-N-Play Audio Amplifier Evaluation Platform is a quick and easy way to connect power, signal and control inputs, and signal outputs to the EVM using standard connectors. However, the audio amplifier evaluation module can be used stand-alone by making connections directly to the module pins, and it can be wired directly into existing circuits or equipment.

The platform switch and jumper settings shown in Table 2–1 are typical for the TPA005D02 class D EVM.

Table 2–1. Typical TI Plug-N-Play Platform Jumper and Switch Settings for the TPA005D02 Class D EVM

EVM	JP6	JP7	JP8	S2	S3
P-N-P Platform	Mute	X	Lo	Note 2	U5

Notes: 1) X = Don't care

2) Set S2 to ON when signal conditioning board is installed in U1; set S2 to OFF when no signal conditioning board is installed.

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2.1 Precautions

Power Supply Input Polarity and Maximum Voltage

Always ensure that the polarity and voltage of the external power connected to V_{CC} power input connector J1, J2, and/or V_{DD} power input connector J6 are correct. Overvoltage or reverse-polarity power applied to these terminals can open onboard soldered-in fuses and cause other damage to the platform, installed evaluation modules, and/or the power source.

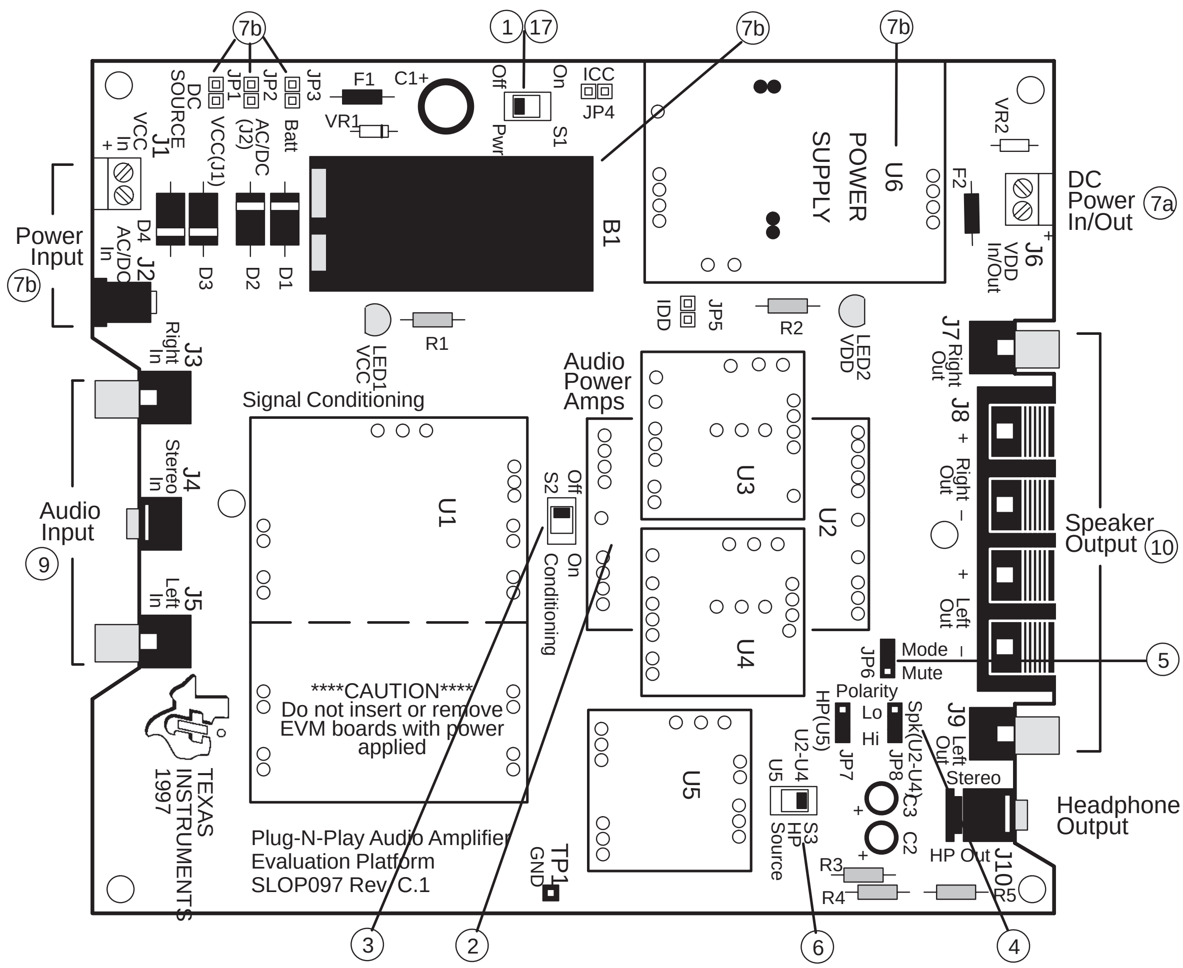
CAUTION

Inserting or Removing EVM Boards

Do not insert or remove EVM boards with power applied — damage to the EVM board, the platform, or both may result.

CAUTION

Figure 2–1. Quick Start Platform Map



2.2 Quick Start List for Platform

Follow these steps when using the TPA005D02 class D EVM with the TI Plug-N-Play Audio Amplifier Evaluation Platform (see the platform user's guide, SLOU011, for additional details). Numbered callouts for selected steps are shown in Figure 2–1 and details appear in Chapter 3.

❑ **Platform Preparations**

1) Ensure that all external power sources are set to ***OFF*** and that the platform power switch **S1** is set to ***OFF.***
2) Install a TPA005D02 module in platform socket **U2,** taking care to align the module pins correctly.
3) Use switch **S2** to select or bypass the signal conditioning EVM (**U1**).
4) Set control signal **Polarity** jumper **JP8** to ***Lo.***
5) Set jumper **JP6** to select the ***Mute*** control input (causes the TPA005D02 to mute if a plug is inserted into platform headphone jack **J10**).
6) Set switch **S3** to ***U5.*** It is important that S3 always be in the U5 position to avoid possible damage to the EVM and headphones when the TPA005D02 class D EVM is installed in platform socket U2.

Table 2–2. Platform Jumper and Switch Settings for the TPA005D02

EVM	JP6	JP7	JP8	S2	S3
P-N-P Platform	Mute	X	Lo	Note 2	U5

Notes: 1) X = Don't care
2) Set **S2** to ***ON*** when signal conditioning board is installed in **U1**; set **S2** to ***OFF*** when no signal conditioning board is installed.

❑ **Power supply**

7) Select and connect the power supply (ensure power supply is set to ***OFF***):
   a) Connect an external regulated power supply set to 5 V to platform V_{DD} power input connector **J6** taking care to observe marked polarity, or
   b) Install a voltage regulator EVM (SLVP097 or equiv.) in platform socket **U6**. Connect a 7 V – 12 V power source to a platform V_{CC} power input **J1** or **J2** and jumper the appropriate power input (see platform user's guide).

❑ **Inputs and outputs**

8) Ensure that the audio signal source level is set to minimum.
9) Connect the audio source to left and right RCA phono jacks **J3** and **J5** or stereo miniature phone jack **J4.**
10) Connect 4-Ω – 8-Ω speakers (use 4-Ω for best performance) to left and right RCA jacks **J7** and **J9** or to stripped wire speaker connectors **J8.**

❑ **Power Up**

11) Verify correct voltage and input polarity and set the external power supply to ***ON.*** If V_{CC} and an onboard regulator EVM are used to provide V_{DD}, set platform power switch **S1** to ***ON.***

Platform LED2 should light indicating the presence of V_{DD}, and the evaluation modules installed on the platform should begin operation.

12) Adjust the signal source level as needed.

2.3 Quick Start List for Stand-Alone

Follow these steps to use the TPA005D02 class D EVM stand-alone or to connect it into existing circuits or equipment. Connections to the TPA005D02 module header pins can be made via individual sockets, wire-wrapping, or soldering to the pins, either on the top or the bottom of the module circuit board.

❑ **Power supply**

1) Ensure that all external power sources are set to ***OFF.***

2) Connect an external regulated power supply set to 5 V to the module **VDD** and **GND** pins taking care to observe marked polarity. Separate right channel and left channel VDD supplies can be connected, or a single supply can be used for both.

❑ **Inputs and outputs**

3) Ensure that audio signal source level adjustments are set to minimum.

4) Connect the audio source to the module **RIN+/RIN–** and **LIN+/LIN–** pins, taking care to observe marked polarity.

5) Connect a control signal to the module **MUTE** pin, if necessary. The control signal should be high or floating for normal operation and low to mute the module.

6) Connect a 4-Ω – 8-Ω speaker (use 4-Ω for best performance) to the module **ROUT+/ROUT–** pins and another speaker to the **LOUT+/LOUT–** pins, taking care to observe marked polarity.

❑ **Power-up**

7) Verify correct voltage and input polarity and set the external power supply to ***ON.***

The EVM should begin operation.

8) Adjust the signal source level as needed.

Chapter 3

Details

This chapter provides details on the TPA005D02 IC, the evaluation module, and the steps in the Quick-Start List, a discussion on class D amplifiers, additional application information, a parts list for the TPA005D02 class D evaluation module, module performance graphs, and module PCB layer illustrations.

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3.1 Precautions

Power Supply Input Polarity and Maximum Voltage

Always ensure that the polarity and voltage of the external power connected to V_{CC} power input connector J1, J2, and/or V_{DD} power input connector J6 are correct. Overvoltage or reverse-polarity power applied to these terminals can open onboard soldered-in fuses and cause other damage to the platform, installed evaluation modules, and/or the power source.

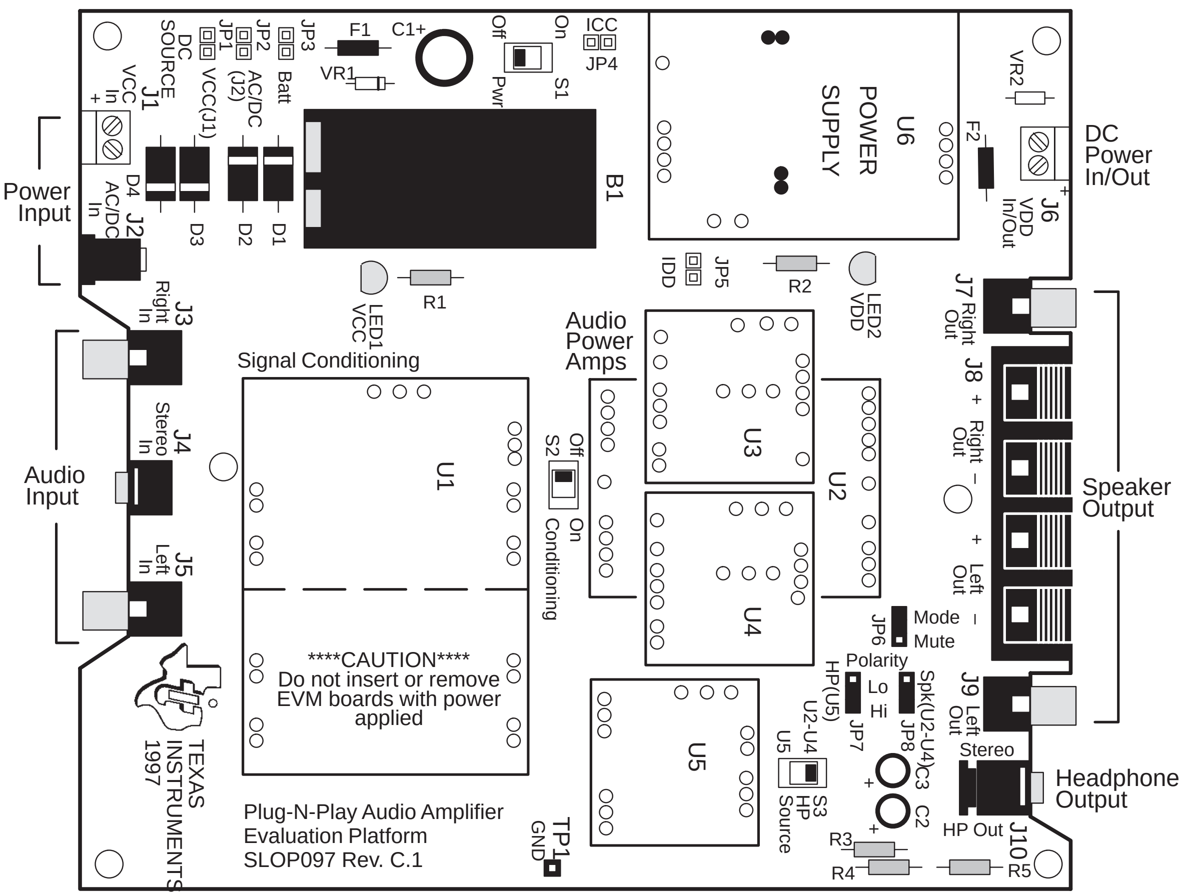
CAUTION

Inserting or Removing EVM Boards

Do not insert or remove EVM boards with power applied — damage to the EVM board, the platform, or both may result.

CAUTION

Figure 3–1. The TI Plug-N-Play Audio Amplifier Evaluation Platform



3.2 The TPA005D02 Audio Power Amplifier Evaluation Module

The TPA005D02 Class D Stereo Audio Power Amplifier Evaluation Module is powered by a TPA005D02 class D stereo power amplifier integrated circuit capable of delivering greater than 2 W of continuous power per channel into 4-Ω loads. The amplifier IC operates in the bridge-tied load mode for maximum efficiency. The evaluation module includes onboard switches for muting and shutdown and a control input pin for muting. A pair of indicator LEDs are mounted on the module to display power supply undervoltage and amplifier IC thermal status.

The module can be used with the TI Plug-N-Play Audio Amplifier Evaluation Platform (Figure 3–1) or wired directly into circuits or equipment. The module has single in-line header connector pins mounted to the underside of the board. These pins allow the module to be plugged into the TI platform, which automatically makes all the signal input and output, power, and control connections to the module.

The module connection pins are on 0.1-inch centers to allow easy use with standard perf board and plug board-based prototyping systems. Or, the EVM can be wired directly into existing circuits and equipment when used stand-alone.

The module appears in Figure 3–2 and its schematic is shown in Figure 3–3.

Figure 3–2. TPA005D02 Class D EVM

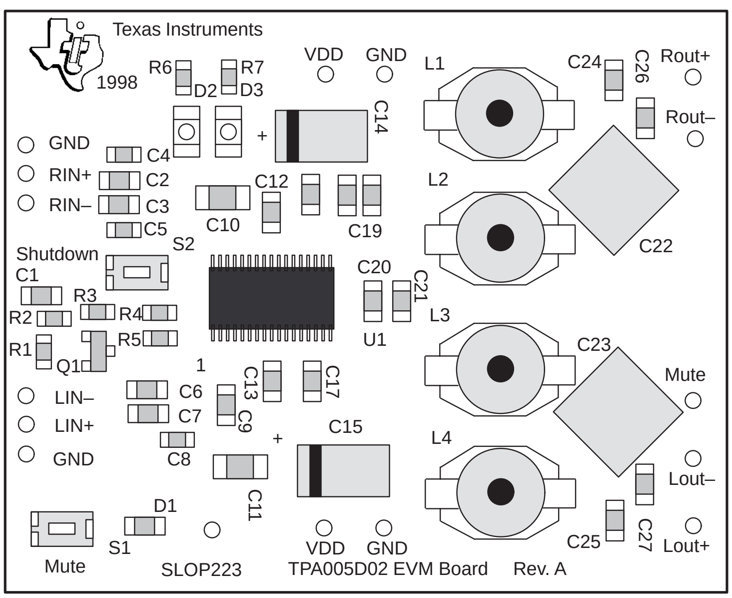
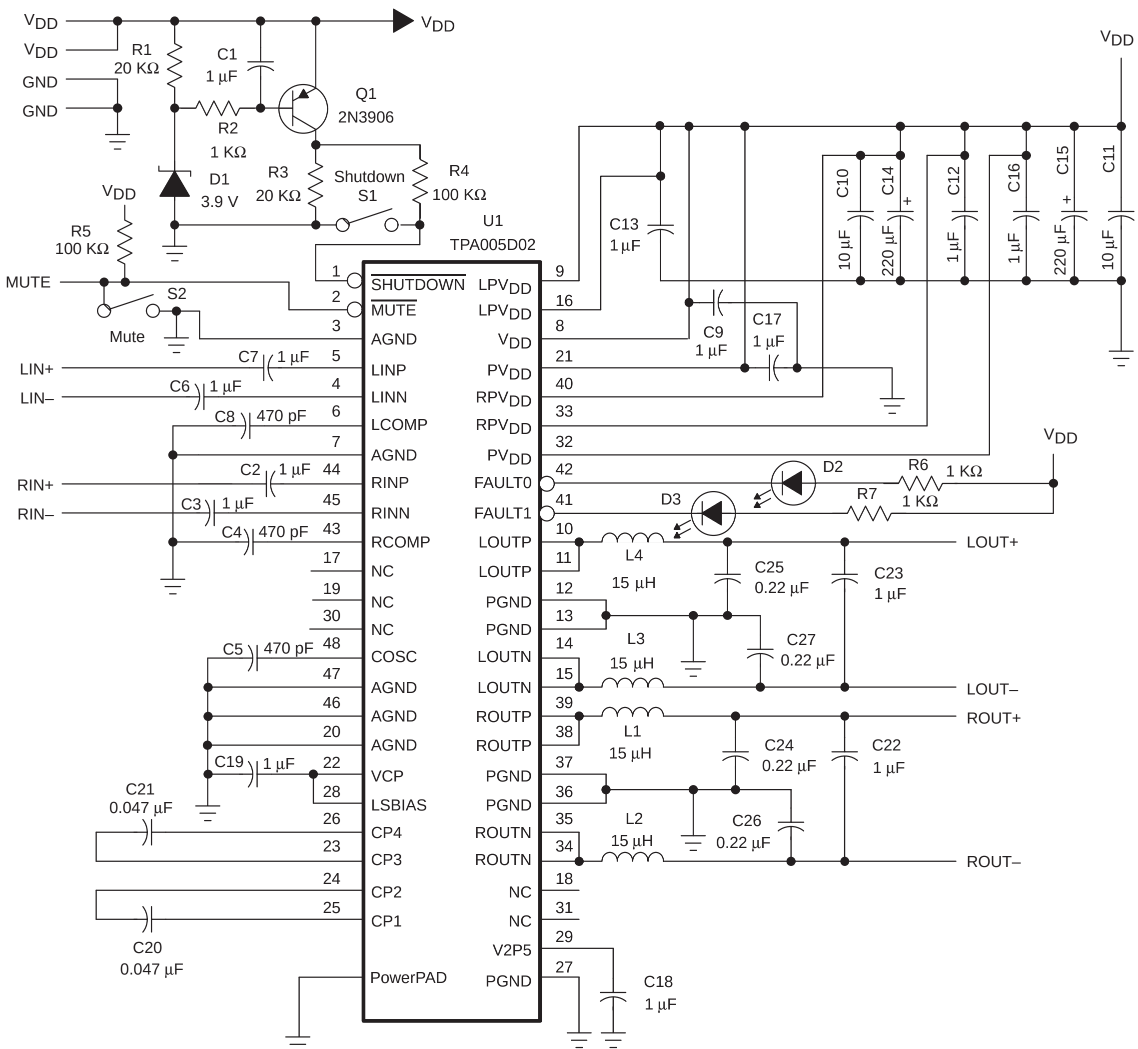


Figure 3–3. TPA005D02 Class D EVM Schematic Diagram



3.2.1 TPA005D02 Class D Stereo Audio Amplifier IC

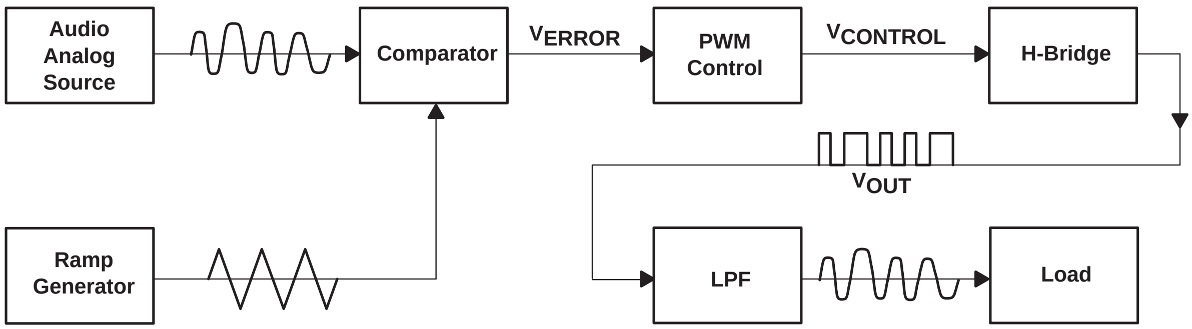
The TPA005D02 Class D Stereo Audio Power Amplifier integrated circuit converts low-level audio into pulse-width-modulated (PWM) signals, which result in an audio output with a 24-dB increase in amplitude. Designed primarily for BTL operation at a supply voltage of 5 V, each channel of the TPA005D02 amplifier IC is capable of 2 W of continuous output power into a 4-Ω load at 0.8% total harmonic distortion + noise (THD+N) over a frequency range of 20Hz – 20kHz.

The device is provided in a very small 48-pin thermally-enhanced PowerPAD TSSOP surface-mount package (DCA) and consumes only 400 µA in shutdown mode, making the TPA005D02 an excellent choice for portable battery-powered applications.

3.2.2 Overview of Class D Audio Amplifiers

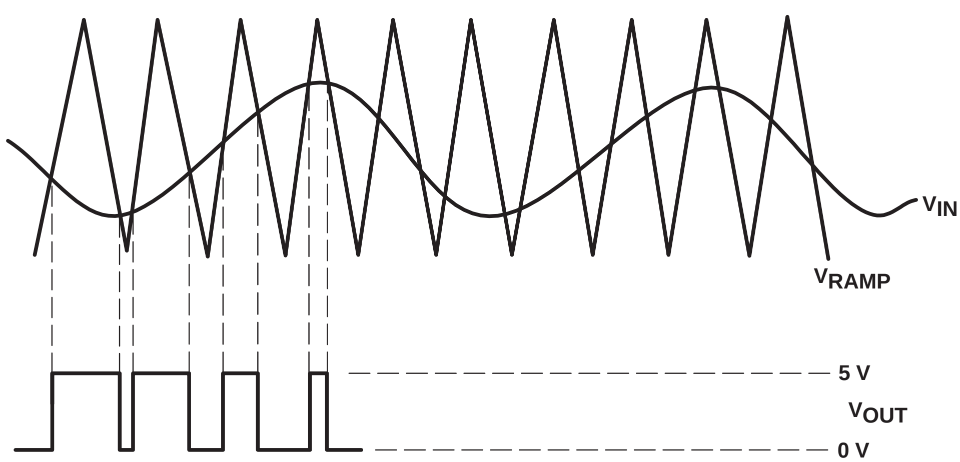
Class D audio amplifiers are very similar in operation to switch-mode power supplies in that both compare an input signal with a reference to create an error voltage that controls a pulse-width modulator (PWM) circuit. The PWM then produces an output signal at constant frequency and with a duty cycle that varies according to the input signal. This controls the switching action of the output power stage (H-bridge). A block diagram of the major components that make up the amplifier is shown in Figure 3–4.

Figure 3–4. Class D Functional Diagram



The audio input signal (V_{in}) is applied to a comparator along with a triangle wave created by the ramp generator (V_{ramp}). When the triangle wave crosses the audio input on the rising and falling ramps, the comparator sends an error signal to the PWM control circuit. The PWM signal regulates the duty cycle of the H-bridge circuit to provide V_{out}. Examples of these waveforms are shown in Figure 3–5.

Figure 3–5. Class D Input and Output Waveforms



The triangle wave must be operating at a much higher frequency than the highest frequency component of the input signal in order to get an accurate representation at the amplifier output. The TPA005D02 EVM uses a 250 kHz switching rate to sample the input, which is more than ten times higher than the highest frequency component of the 20 Hz to 20kHz audio input range.

The H-bridge circuit consists of DMOS power transistors for supplying the heavy currents which are required by the load. These transistors operate in either the cutoff or saturation regions rather than the linear region in which class AB amplifiers operate. Switching and conduction losses are reduced since the transistor is active for only a small part of the duty cycle, reducing the power dissipated by the power transistors and allowing more power to be delivered to the load. A low pass filter (LPF) then removes the high frequency switching component from the output signal, leaving an amplified version of the original input signal. The DMOS transistors are arranged in an H-bridge (full bridge) configuration to allow BTL operation, which further enhances the amplifier performance.

3.2.2.1 BTL Operation

In the bridge-tied load output mode, the two output lines of each channel operate as mirror images of each other for increased power. The speaker load is connected directly across OUT+ and OUT–, and neither line is connected to ground. BTL operation provides many benefits, including quadruple the output power of single-ended operation and no need for bulky output coupling capacitors. For more information, see the TPA005D02 amplifier IC data sheet, TI Literature Number SLOS205.

To operate in the bridge-tied load output mode, the module output signal from OUT+ must go through the speaker load and be returned directly to OUT–, and ***NOT*** to system ground. This requires that the OUT– line be isolated not only from system ground, but also from the OUT– lines of any other amplifiers in the system. The platform provides such isolated output lines from the amplifier EVM sockets directly to separate left and right speaker connectors.

3.2.3 EVM Design Considerations

Circuit design and layout plays a large role in the creation or reduction of distortion in class D amplifiers, and the high frequency switching characteristics of class D audio power amplifier output stages offer some interesting design challenges over conventional class AB amplifiers.

The main goal of the design of this EVM is to offer the best performance with the smallest components, without sacrificing performance. For this reason surface mount technology (SMT) parts are used whenever possible. The major design considerations are discussed below and refer to Figures 3–2 and 3–3 unless otherwise noted. The actual parts used in the EVM are listed in Table 3–3.

The audio signal path is the most critical, so the discussion begins there.

3.2.3.1 Input Filter

The first consideration is the desired frequency bandwidth (BW). High-fidelity audio requires a flat 20Hz to 20kHz bandwidth. The low frequency –3-dB point is set using an ac coupling capacitor at the amplifier inputs (IC pins 4, 5, 44, and 45) which creates a high-pass filter (HPF). The –3-dB point for a first-order HPF is found using the equation

$$f_{LO} = \frac{1}{(2\pi RC)}$$

where R = 10 kΩ is the input resistance of the amplifier and C = 1 µF for the value of capacitors C2, C3, C6, and C7. These values give a –3-dB point of 15.9 Hz—close to the desired –3-dB point of 20 Hz. Ceramic capacitors are preferred over electrolytic for their small size, low equivalent series resistance (ESR), low noise, and long life. The smallest ceramic SMT package currently available is 0603, yet availability necessitates using an 0805 package.

Other considerations are stability over temperature, voltage rating, and cost. A tradeoff exists between the size, temperature characteristics, rated voltage, and capacitance value. For a given package size, for example, an increase in the voltage rating means a decrease in capacitance. The same applies to improved temperature stability.

Temperature stability has little impact on the input capacitors since they primarily couple the ac input signal and are not expected to dissipate large amounts of heat. The input voltage is low for the class D EVM (less than 0.5 Vrms), so the rated voltage can also be low. An 0805 SMT package with a rated voltage of 5 V and Y5V temperature characteristics would be ideal for this application. Availability and cost constraints, however, dictated the use of the power supply bypass capacitors that were finally selected, which meet all requirements and are rated at 16V. If better matching of the left and right channels is needed or a harsh environment will be encountered, then a capacitor with X7R temperature characteristics should be considered.

3.2.3.2 Output Filter

Class D amplifiers require special filtering at the output to remove the high-frequency switching component and accurately reconstruct the audio signal. The output filter is a low-pass filter (LPF) which sets the high frequency –3-dB point of the bandwidth. The major consideration here is how to choose the components and set the desired –3-dB point.

Filter Design Goals

A second-order low-pass filter is used for the output filter. The Butterworth filter is characterized by a flat response over the pass band and less attenuation after the cutoff frequency. The order of the filter determines how many poles exist that are at the same frequency, with each pole providing –20 dB per decade of signal attenuation for a total of –40 dB per decade in this circuit. The cutoff frequency (f_C) can be determined using the equation

$$f_C = \frac{1}{(2\pi\sqrt{LC})}$$

where L is the inductance and C is the equivalent capacitance. The values used in the output filter are 15 μH for the inductor, and 0.22 μF and 1 μF capacitors in parallel for an equivalent capacitance of 2.22 μF, setting the cutoff frequency to 27.5 kHz. The main purpose of this filter is to reduce the switching frequency to an acceptable level and not attenuate the audio band. The 250 kHz amplifier output signal is then reduced by –40 dB to one percent of its pre-filter value.

The considerations for inductor selection are inductance, continuous and peak current ratings, dc series resistance, and the packaging. The inductance was chosen based on common inductance and capacitance values, to be 15 μH.

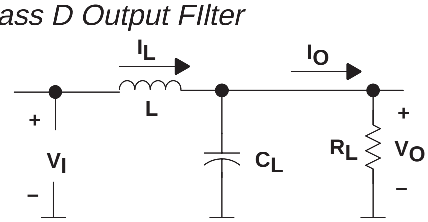
Class D Output Filter Design Methodology

The output filter attenuates the high switching frequency. A second-order Butterworth low-pass filter was chosen for its flat pass band, good phase response, and low parts count (it requires only an inductor and a capacitor). The normalized transfer for the Butterworth filter is

$$H(s) = \frac{1}{s^2 + \sqrt{2}s + 1}$$

The next step is to realize the circuit and develop a transfer function. The filter for a single-ended application is shown in Figure 3–6.

Figure 3–6. Single-Ended Class D Output FIlter



The transfer function is easily derived by using a voltage divider equation with the load voltage being a parallel combination of R_L and C_L. This transfer function is

$$\frac{V_O(s)}{V_I(s)} = \frac{\frac{1}{LC_L}}{S^2 + \frac{1}{R_L C_L} \times S + \frac{1}{LC_L}}$$

The next step is to set the terms of the circuit transfer function equal to the terms of the normalized 2nd-order Butterworth low-pass filter and solve for L and C_L in terms of R_L. This yields

$$C_L = \frac{1}{\sqrt{2} \times R_L}$$

$$L = \sqrt{2} \times R_L$$

These values give a cut-off frequency at ω_0 = 1 radian/second, which means that the components must be frequency scaled. To frequency scale, each component is divided by $\omega_0 = 2 \times \pi \times f_c$ (f_c is the desired cut-off frequency in Hertz):

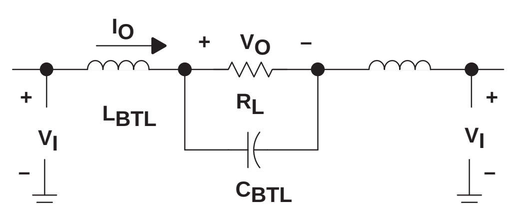
$$C_{SE} = \frac{1}{\sqrt{2} \times R_L \times \omega_0}$$

$$L_{SE} = \frac{\sqrt{2} \times R_L}{\omega_o}$$

$$\omega_0 = 2 \times \pi \times f_c$$

Because the TPA005D02 is a bridged amplifier, this filter is needed at both the positive and negative output. This means that R_L must be split between each filter, so for a bridged application, R_L must be divided by 2 in the component calculations. One capacitor can be used in place of the two capacitors in the output filters if the capacitor is placed across R_L instead of from each side of R_L to ground. This circuit is shown in Figure 3–7.

Figure 3–7. Low-Pass Filter for Bridged Application



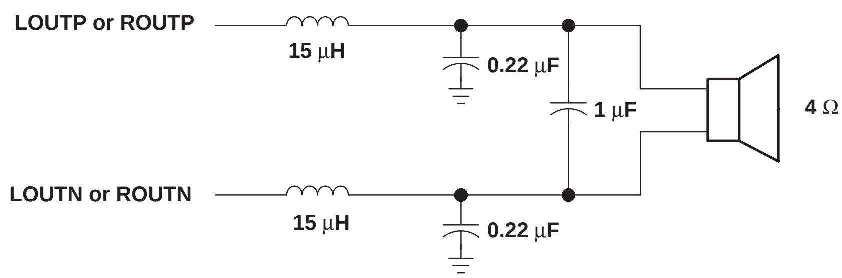
The component equations adjusted for bridged amplifiers are

$$C_{BTL} = \frac{1}{\sqrt{2} \times R_L \times \omega_0}$$

$$L_{BTL} = \frac{\sqrt{2} \times R_L}{2 \times \omega_0}$$

To find component values, let f_c = 30 kHz, which yields ω_0 = 188495.6 radians/second. If a 4-Ω speaker is used, R_L = 4 Ω. This yields L_{BTL} = 15 µH and C_{BTL} = 0.94 µF. Additional capacitors can be added from each side of R_L to ground to provide a high-frequency short to ground. These additional capacitors should be approximately 10% of $2C_{BTL}$. The resulting output filter is shown in Figure 3–8 with the components rounded to standard values.

Figure 3–8. Resulting Bridged Output Filter



Output Filter Components

The output inductors are key elements in the performance of the class D audio amplifier system. It is important that these inductors have a high enough current rating and a relatively constant inductance over frequency and temperature. The current rating should be higher than the maximum current expected to avoid magnetically saturating the inductor. When saturation occurs, the inductor loses its functionality and looks like a short circuit to the PWM signal, which increases the harmonic distortion considerably.

A shielded inductor may be required if the class D amplifier is placed in an EMI sensitive system; however, the switching frequency is low for EMI considerations and should not be an issue in most systems. The DC series resistance of the inductor should be low to minimize losses due to power dissipation in the inductor, which reduces the efficiency of the circuit.

Capacitors are important in attenuating the switching frequency and high frequency noise, and in supplying some of the current to the load. It is best to use capacitors with low equivalent-series-resistance (ESR). A low ESR means that less power is dissipated in the capacitor as it shunts the high-frequency signals. Ceramic (C24, C25, C26, and C27) and metal film (C22 and C23) capacitors were selected because of their low ESR. Placing these capacitors in parallel also parallels their ESR, effectively reducing the overall ESR value. The voltage rating is also important, and, as a rule of thumb, should be 2 to 3 times the maximum rms voltage expected to allow for high peak voltages and transient spikes. These output filter capacitors should be stable over temperature since large currents flow through them.

3.2.3.3 Power Filtering

Power supply considerations include power supply decoupling and high frequency bypass loops. Electrolytic capacitors are used for decoupling and ceramic or mica capacitors are used for high frequency bypass applications.

Decoupling capacitors serve to smooth the input voltage and assist the amplifier by providing current when needed. These capacitors may shunt relatively large ripple currents to ground and must have a low equivalent series resistance (ESR) to reduce power and heat dissipation in the device. The ESR combines all losses, both series and parallel, in a capacitor at a given frequency in order to reduce the equivalent circuit to a simple RC series connection, valid only for low frequencies (less than 1 MHz).

Other considerations are the voltage rating, capacitance, physical size, and the specific type of capacitor. The voltage rating should exceed the maximum supply voltage expected in order to handle voltage surges and spikes without being damaged. The capacitance is then important, as it specifies the amount of energy that can be stored in the capacitor. Once the voltage rating and capacitance are known, the size can be determined.

Since the focus was to get the largest capacitance possible yet keep the size to a minimum, tantalum capacitors, instead of aluminum electrolytic capacitors, were chosen. Tantalum capacitors provide a higher capacitance value in a smaller package and have lower ESR values than aluminum electrolytic capacitors. SMT packages further reduce the inductance associated with lead lengths. All of these considerations led to the selection of a 220 μF SMT tantalum capacitor as the primary decoupling capacitor.

The high frequency bypass capacitors are usually small in size, limited by the size of the capacitance to approximately 10 μF or less. Ceramic capacitors have extremely low ESR and dissipate very little power. Lower ESR means a lower net impedance at higher frequencies, which is more suitable for filtering the higher frequency components of the power supply, especially voltage spikes. Bypass capacitors should be placed as close as possible to the IC power input pins and also as close to the IC power ground pins as possible. The idea is to form the smallest possible loop, or path, over which the high frequency signals can travel, and minimize the impedance. A short path with a high impedance defeats the purpose.

The power pins (VDD) were placed at the top and bottom of the IC package, and the power traces and filtering capacitors were arranged to balance the left and right channels of the IC. A trace along the bottom of the board links the V_{DD} pins for EVM stand-alone operation and supplies power to the right and left channels in parallel. This places the capacitors and their ESR in parallel, increasing the overall capacitance seen by the power source while greatly reducing the ESR.

3.2.3.4 Ground Plane

Experimentation with several types of ground planes has shown that a solid ground plane works as well as methods that split the analog and power ground planes when good layout practices are followed. This allows a much simpler design that requires less time and is less prone to layout errors. The success of the solid ground plane is partially due to the TPA005D02 IC, which allows the designer to keep the input and output sections of the chip separated, reducing the chance that high- and mid-frequency return currents will make a path to the analog input section of the chip.

The traces for the analog circuit grounds are extremely short and are connected to the ground immediately under the chip through vias, while the power circuit grounds are connected to the ground plane slightly further out from the chip and closer to the signal outputs and power inputs. The large current traces of the output are then shielded from the input circuit by the ground plane.

The solid ground plane has low resistance compared with the narrow paths to pins and vias that are attached. If a voltage spike or current spike hits the ground plane, the entire plane shifts up or down, unlike a split plane, which has inductance between the halves that dampens the noise and can cause uneven voltage potentials to exist.

3.2.3.5 Compensation, Ramp Generator, and Charge Pump Capacitors

The components (C19, C5, C4 and C8) for these circuits are critical to the operation of the TPA005D02 amplifier. The capacitance at these nodes must be close to the specified value and maintain this value over EVM temperature extremes. Ceramic capacitors with X7R temperature characteristics should be used for their low ESR and their stability over a wide temperature range. Tight tolerances are needed, especially for RCOMP (C4) and LCOMP (C8), which need to track closely for good left and right channel matching. A high voltage rating is not needed (15 V would work), yet 50 V is one of the lowest ratings for the size and type of capacitor selected.

Ramp generator capacitor C5 does not need the tight capacitance value tolerance that C4 and C8 require; however, capacitance stability over temperature change is important.

Charge pump capacitor C19 has the same requirements as the ramp generator capacitor (C5), though the size is much larger and the necessary voltage rating due to the charge tripling is increased, making the part somewhat less readily available.

3.2.3.6 Control and Indicator Circuits

The shutdown circuit, the mute circuit, and the fault indicator circuit are all low-current circuits and are not as critical in the layout design as the circuits mentioned previously.

Shutdown

The shutdown control (IC pin 1) is activated by a logic low. Shutdown limits the supply current of the TPA005D02 to 400 μA to conserve power in low power applications.

The shutdown circuit (IC pin 1) consists of D1, Q1, R1, R2, R3, R4, C1, and S2, a relatively large number of components. Since space and power consumption are to be minimized, these components need to be small, low-power devices. Switch S2 is actually the component that sends the device into shutdown mode—there is no shutdown control input pin on the EVM. The remaining components form a delay circuit that eliminates noise created by the discharge of energy stored in the output filter when the amplifier IC is initially placed in shutdown.

The PNP transistor needs to be biased so that it is operational from at least 4.5 V to 5.5 V. Zener diode D1 and resistors R1, R2, and R3 set the bias for the transistor so that it is kept in its linear region and minimizes the supply current used by this circuit. The maximum zener voltage Vz is then calculated to be

$$Vz = V_{DD(min)} – V_{BE(min)} = 4.5V – 0.6V = 3.9V$$

Zener diode D1 was selected based on Vz and the current required for operation. Resistor R1 limits the current through the diode, while R2 also helps limit the base current and isolate the bootstrap capacitor C1. Resistor R3 limits the collector current during normal operation, and R4 limits the current flowing to ground when switch S2 is closed.

Mute

The mute control (IC pin 2) is activated by a logic low, in which case the amplifier low-side output transistors are turned on, shorting the load to ground. The main consideration is to minimize the current used. A 100-kΩ pullup resistor is used to limit the current to microamps and minimize the power dissipated in the resistor, allowing a smaller surface-mount package to be used.

Fault Indicator

The TPA005D02 IC has two fault indicator pins (IC pins 41 and 42) to indicate an under-voltage condition or a thermal fault. When the device is operating normally, both pins are pulled up to the supply voltage through R6/D2 and R7/D3. If the power supply voltage drops too low, the charge pump voltage drops below the operational threshold and the low-side transistors short to ground. When this occurs, IC pin 41 goes to ground, creating a voltage drop across the LED, causing it to illuminate. The LED remains lit until the fault circuit is reset by cycling the power or operating the shutdown or mute switch.

Table 3–1. TPA005D02 Class D EVM Fault Indicator Table

LED 1	LED 2	Fault Description
OFF	OFF	No faults—device is operating normally
OFF	ON	Under-voltage condition
ON	ON	Thermal fault

The fault indicator circuits (IC pins 41 and 42) are designed to minimize current consumption and yet have an LED that is clearly visible when illuminated. The LED should be as small as possible, have a wide viewing angle, and be bright enough to clearly see while using minimal current. The LEDs selected require a 2.1-V drop when activated, and approximately 3 mA of current to be fully illuminated. The current-limit resistance needed is then calculated:

$$R = \frac{V_{DD} - V_d}{I_d} = 967\ \Omega$$

A 1-kΩ resistor was used for R6 and R7. Tests demonstrate that the LEDs selected operate as expected and are clearly visible when the fault circuit is activated.

3.2.4 Efficiency of Class D vs. Linear Operation

Amplifier efficiency is defined as the ratio of output power delivered to the load to power drawn from the supply. In the efficiency equation below, P_L is power across the load and P_{SUP} is the supply power.

$$\text{Efficiency} = \eta = \frac{P_L}{P_{SUP}}$$

A high-efficiency amplifier has a number of advantages over one with lower efficiency. One of these advantages is a lower power requirement for a given output, which translates into less waste heat that must be removed from the device, smaller power supply required, and increased battery life.

Audio power amplifier systems have traditionally used linear amplifiers, which are well known for being inefficient. Class D amplifiers were developed as a means to increase the efficiency of audio power amplifier systems.

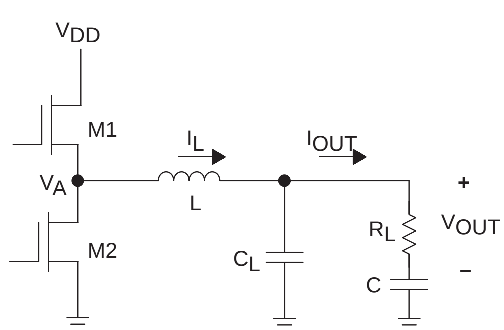
A linear amplifier is designed to act as a variable resistor network between the power supply and the load. The transistors operate in their linear region and voltage that is dropped across the transistors (in their role as variable resistors) is lost as heat, particularly in the output transistors.

The output transistors of a class D amplifier switch from full OFF to full ON (saturated) and then back again, spending very little time in the linear region in between. As a result, very little power is lost to heat because the transistors are not operated in their linear region. If the transistors have a low ON resistance, little voltage is dropped across them, further reducing losses. The ideal class D amplifier is 100% efficient, which assumes that both the ON resistance ($R_{DS(ON)}$) and the switching times of the output transistors are zero.

3.2.4.1 The Ideal Class D Amplifier

To illustrate how the output transistors of a class D amplifier operate, a half-bridge application is examined first (Figure 3–9).

Figure 3–9. Half-Bridge Class D Output Stage



Figures 3–10 and 3–11 show the currents and voltages of the half-bridge circuit. When transistor M1 is on and M2 is off, the inductor current is approximately equal to the supply current. When M2 switches on and M1 switches off, the supply current drops to zero, but the inductor keeps the inductor current from dropping. The additional inductor current is flowing through M2 from ground. This means that V_A (the voltage at the drain of M2, as shown in Figure 3–9) transitions between the supply voltage and slightly below ground. The inductor and capacitor form a low-pass filter, which makes the output current equal to the average of the inductor current. The low pass filter averages V_A, which makes V_{OUT} equal to the supply voltage multiplied by the duty cycle.

Control logic is used to adjust the output power, and both transistors are never on at the same time. If the output voltage is rising, M1 is on for a longer period of time than M2.

Figure 3–10. Class D Currents

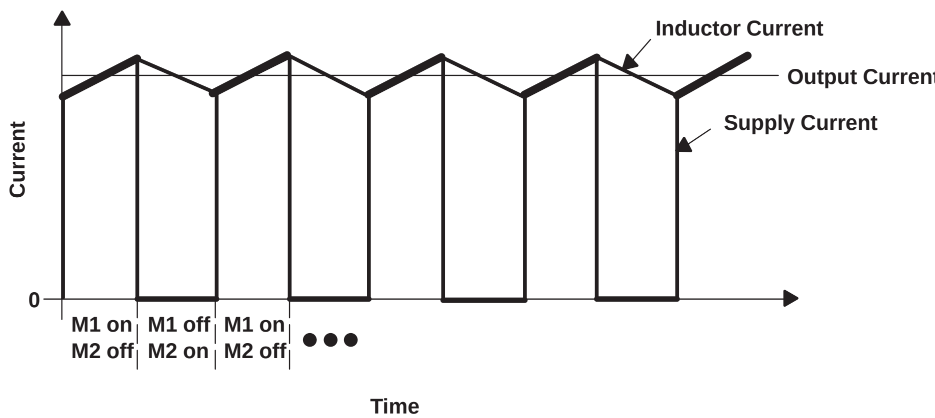
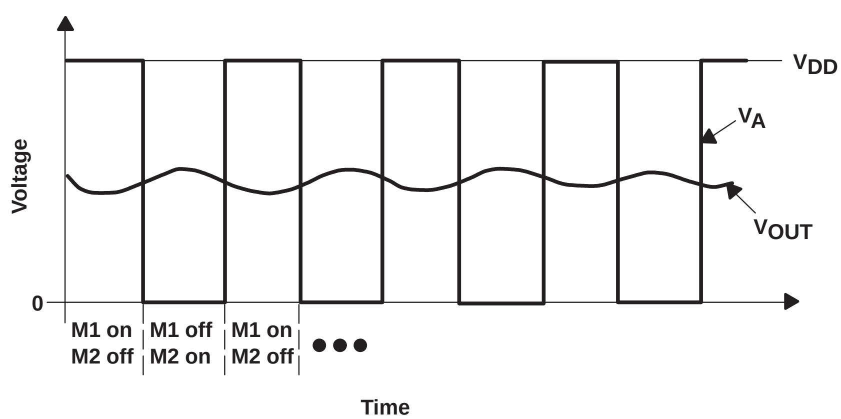


Figure 3–11. Class D Voltages



Given these plots, the efficiency of the class D device can be calculated and compared to an ideal linear amplifier device. In the derivation below, a sine wave of peak voltage (V_P) is the output from an ideal class D and linear amplifier and the efficiency is calculated.

CLASS D

$$V_{L(rms)} = \frac{V_P}{\sqrt{2}}$$

$$\text{Average}\left(I_{DD}\right) = \frac{I_{L(rms)} \times V_{L(rms)}}{V_{DD}}$$

$$P_L = V_L \times I_L$$

$$P_{SUP} = V_{DD} \times \text{Average}\left(I_{DD}\right)$$

$$P_{SUP} = \frac{V_{DD} \times I_{L(rms)} \times V_{L(rms)}}{V_{DD}}$$

$$\text{Efficiency} = \eta = \frac{P_L}{P_{SUP}}$$

$$\text{Efficiency} = \eta = 1$$

LINEAR

$$V_{L(rms)} = \frac{V_P}{\sqrt{2}}$$

$$P_L = \frac{{V_{L(rms)}}^2}{R_L} = \frac{{V_P}^2}{2\ R_L}$$

$$\text{Average}\left(I_{DD}\right) = \frac{2}{\pi} \times \frac{V_P}{R_L}$$

$$P_{SUP} = V_{DD} \times \text{Average}\left(I_{DD}\right) = \frac{V_{DD}\ V_P}{R_L} \times \frac{2}{\pi}$$

$$\text{Efficiency} = \eta = \frac{P_L}{P_{SUP}}$$

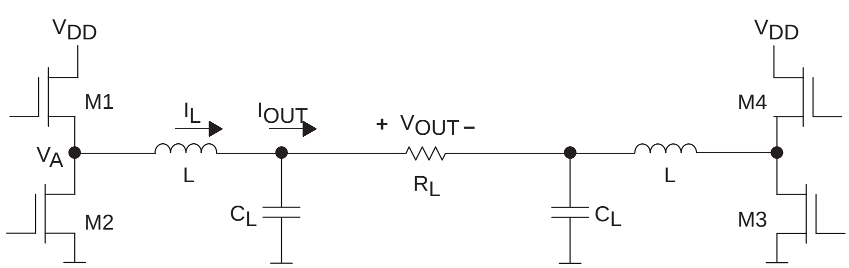
$$\text{Efficiency} = \eta = V_{DD} \times \frac{\frac{{V_P}^2}{2R_L}}{\frac{2}{\pi} \times \frac{V_P}{R_L}}$$

$$\text{Efficiency} = \eta = \frac{\pi}{4} \times \frac{V_P}{V_{DD}}$$

In the ideal efficiency equations, assume that $V_P = V_{DD}$, which is the maximum sine wave magnitude without clipping. Then, the highest efficiency that a linear amplifier can have without clipping is 78.5%. A class D amplifier, however, can ideally have an efficiency of 100% at all power levels.

The derivation above applies to an H-bridge as well as a half-bridge. An H-bridge requires approximately twice the supply current but only requires half the supply voltage to achieve the same output power—factors that cancel in the efficiency calculation. The H-bridge circuit is shown in Figure 3–12.

Figure 3–12. H-Bridge Class D Output Stage

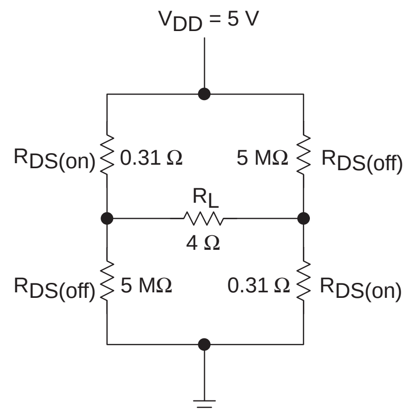


3.2.4.2 Losses in a Real-World Class D Amplifier

Losses make class D amplifiers nonideal, and reduce the efficiency below 100%. These losses are due to the output transistors having a nonzero $R_{DS(on)}$, and rise and fall times that are greater than zero.

The loss due to a nonzero $R_{DS(on)}$ is called conduction loss, and is the power lost in the output transistors at nonswitching times, when the transistor is ON (saturated). Any $R_{DS(on)}$ above 0 Ω causes conduction loss. Figure 3–13 shows an H-bridge output circuit simplified for conduction loss analysis and can be used to determine new efficiencies with conduction losses included.

Figure 3–13. Output Transistor Simplification for Conduction Loss Calculation



The power supplied, P_{SUP}, is determined to be the power output to the load plus the power lost in the transistors, assuming that there are always two transistors on.

$$\text{Efficiency} = \eta = \frac{P_L}{P_{SUP}}$$

$$\text{Efficiency} = \eta = \frac{I^2R_L}{I^2\ 2R_{DS(on)} + I^2R_L}$$

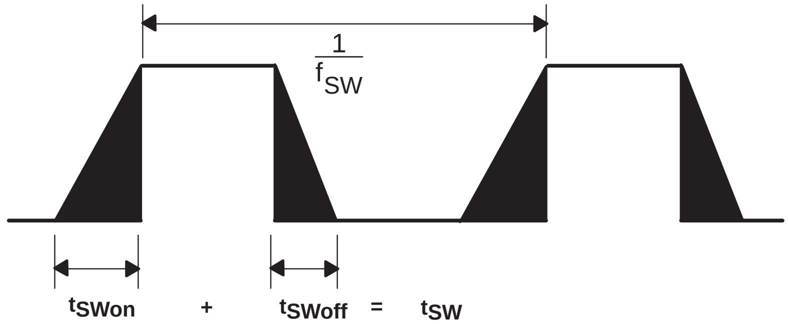
$$\text{Efficiency} = \eta = \frac{R_L}{2R_{DS(on)} + R_L}$$

$$\text{Efficiency} = \eta = 95\% \left(\text{at all output levels } R_{DS(on)} = 0.1,\ R_L = 4\right)$$

$$\text{Efficiency} = \eta = 87\% \left(\text{at all output levels } R_{DS(on)} = 0.31,\ R_L = 4\right)$$

Losses due to rise and fall times are called switching losses. A plot of the output, showing switching losses, is shown in Figure 3–14.

Figure 3–14. Output Switching Losses



Rise and fall times are greater than zero for several reasons. One is that the output transistors cannot switch instantaneously because (assuming a MOSFET) the channel from drain to source requires a specific period of time to form. Another is that transistor gate-source capacitance and parasitic resistance in traces form RC time constants that also increase rise and fall times.

The switching power loss formula below with the following values (V_{DD} = 5V, t_{SW} = 50 ns, f_{SW} = 250 kHz, $R_{DS(on)}$ = 310 mΩ, R_L = 4 Ω) yields a switching power loss of 4.4 mW at all output powers.

$$P_{SW} = \frac{\frac{1}{2} \times t_{SW} \times f_{SW}\left(\frac{V_{DD}\ 2R_{DS(on)}}{R_L + 2R_{DS(on)}}\right)^2}{2R_{DS(on)}}$$

Switching losses are constant at all output power levels, which means that switching losses can be ignored at high power levels in most cases. At low power levels, however, switching losses must be taken into account when calculating efficiency.

3.2.4.3 Class D Effect on Power Supply

Efficiency calculations are an important factor for proper power supply design in amplifier systems. Table 3–2 shows class D efficiency at a range of output power levels (per channel) with a 1-kHz sine wave input. The maximum power supply draw from a stereo 1-W per channel audio system with 8-Ω loads and a 5-V supply is almost 2.7 W. A similar linear amplifier such as the TPA0202 has a maximum draw of 3.25 W under the same circumstances.

Table 3–2. Efficiency vs Output Power in 5-V 8-Ω H-Bridge Systems

Output Power (W)	Efficiency (%)	Peak Voltage (V)	Internal Dissipation (W)
0.25	63.4	2	0.145
0.5	73	2.83	0.183
0.75	77.1	3.46	0.222
1	79.3	4	0.314
1.25	80.6	4.47†	0.3

† High peak voltages cause the THD to increase

There is a minor power supply savings with a class D amplifier versus a linear amplifier when amplifying sine waves. The difference is much larger when the amplifier is used strictly for music. This is because music has much lower RMS output power levels, given the same peak output power (Figure 3–15); and although linear devices are relatively efficient at high RMS output levels, they are very inefficient at mid-to-low RMS power levels. The standard method of comparing the peak power to RMS power for a given signal is crest factor, whose equation is shown below. The lower RMS power for a set peak power results in a higher crest factor

$$\text{Crest Factor} = 10 \log \frac{P_{PK}}{P_{rms}}$$

Figure 3–15. Audio Signal Showing Peak and RMS Power

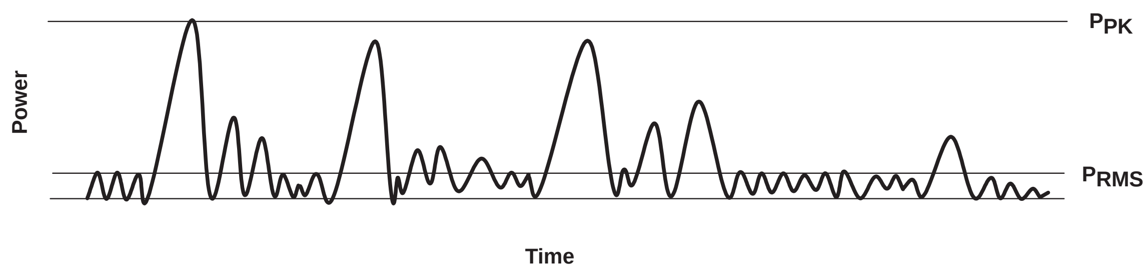
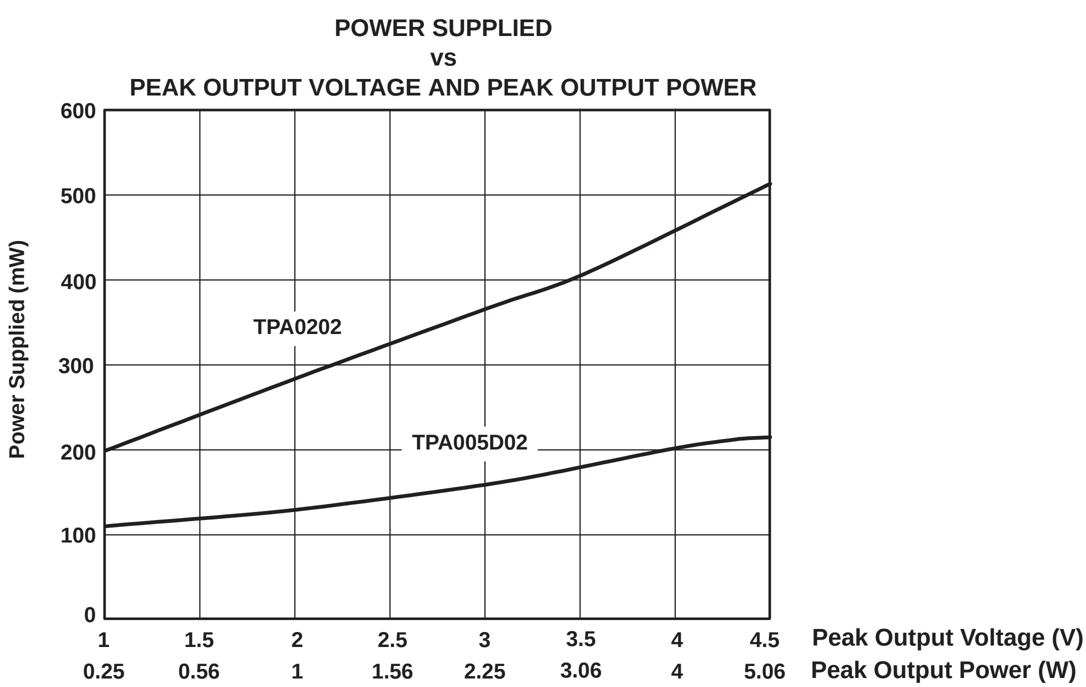


Figure 3–16 is a comparison of a 5-V class D amplifier to a similar linear amplifier playing music that has a 13.76-dB crest factor. From the plot, the power supply draw from a stereo amplifier that is playing music with a 13.76 dB crest factor is 1.02 W, while a class D amplifier draws 420 mW under the same conditions. This means that just under 2.5 times the power supply is required for a linear amplifier over a class D amplifier.

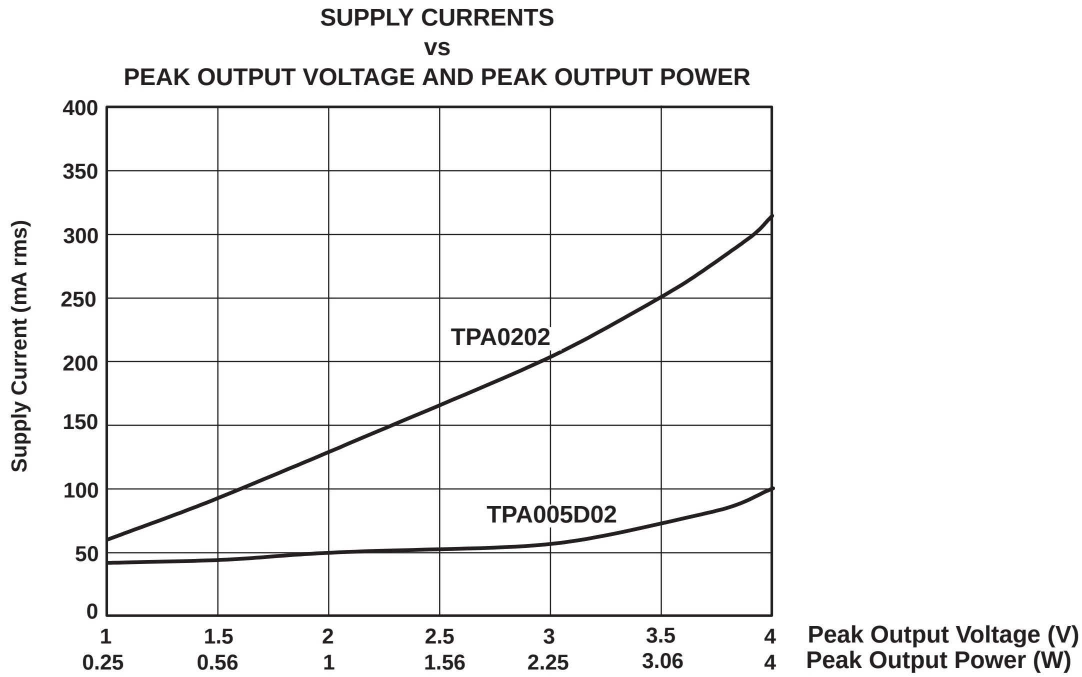
Figure 3–16. Audio Signal Showing Peak and RMS Power (with Music Applied)



3.2.4.4 Class D Effect on Battery Life

Battery operations for class D amplifiers versus linear amplifiers have similar power supply savings. The essential contributing factor to longer battery life is lower RMS supply current. Figure 3–17 compares the TPA005D02 supply current to the supply current of the TPA0202, a 2-W linear device, while playing music at different peak voltage levels.

Figure 3–17. Supply Current vs Peak Output Voltage of TPA005D02 vs TPA0202 with Music Input



This plot shows that a linear amplifier has approximately three times more current draw at normal listening levels than a class D amplifier. Thus, a class D amplifier has approximately three times longer battery life at normal listening levels. If there is other circuitry in the system drawing supply current, that must also be taken into account when estimating battery life savings.

3.3 Using The TPA005D02 Class D EVM With the Plug-N-Play Platform

The TPA005D02 Class D Stereo Audio Amplifier Evaluation Module was designed to be used with the TI Plug-N-Play Audio Amplifier Evaluation Platform. It simply plugs into socket U2.

The following paragraphs provide additional details for using the TPA005D02 class D EVM with the platform.

3.3.1 Installing and Removing EVM Boards

TI Plug-N-Play evaluation modules use single-in-line header pins installed on the underside of the module circuit board to plug into sockets on the platform. The EVM pins and the platform sockets are keyed such that only the correct type of EVM can be installed in a particular socket, and then only with the proper orientation.

Evaluation modules are easily removed from the platform by simply prying them up and lifting them out of their sockets. Care must be taken, however, to prevent bending the pins.

3.3.1.1 EVM Insertion

1) Remove all power from the evaluation platform.
2) Locate socket U2 on the platform.
3) Orient the module correctly.
4) Carefully align the pins of the module with the socket pin receptacles.
5) Gently press the module into place.
6) Check to be sure that all pins are seated properly and that none are bent over.

3.3.1.2 EVM Removal

1) Remove all power from the evaluation platform.
2) Using an appropriate tool as a lever, gently pry up one side of the module a small amount.
3) Change to the opposite side of the module and use the tool to pry that side up a small amount.
4) Alternate between sides, prying the module up a little more each time to avoid bending the pins, until it comes loose from the socket.
5) Lift the EVM off of the platform.

3.3.2 Module Switches

The TPA005D02 Class D Stereo Audio Amplifier Evaluation Module is equipped with two pushbutton switches that allow the module shutdown and mute functions to be manually activated.

3.3.2.1 S1 — Shutdown

To have the module amplifier IC enter the shutdown mode, press the Shutdown switch (S1) on the module. S1 connects the amplifier IC $\overline{\text{SHUTDOWN}}$ pin to ground, forcing it into a low-power state. This function is not controlled by a control input to the module—only by switch S1.

The shutdown mode reduces the amplifier IC current consumption to approximately 400 µA compared to approximately 10 mA in the mute mode.

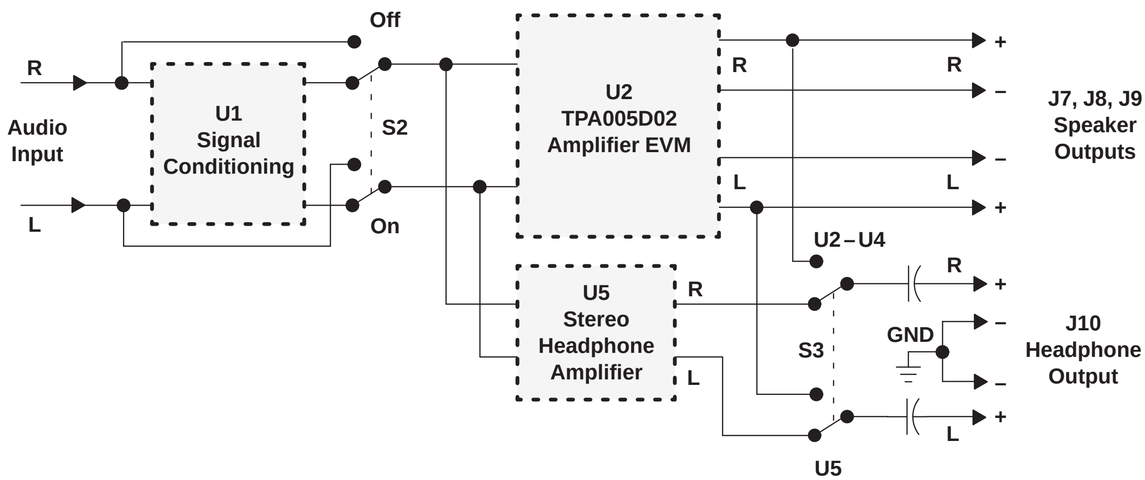
3.3.2.2 S2 — Mute Switch

Pushbutton switch S2 on the TPA005D02 class D EVM allows manual muting of the amplifier IC. S2 connects the amplifier IC $\overline{\text{MUTE}}$ pin to ground, muting the output. The EVM Mute control input pin allows control of this function by the platform or other external circuit.

3.3.3 Signal Routing

Signal flow on the platform is controlled by two signal routing switches, as shown in Figure 3–18.

Figure 3–18. Platform Signal Routing and Outputs



3.3.3.1 Signal Conditioning

The audio signal from input jacks can be applied to the signal conditioning socket (U1) if an EVM is installed there, or socket U1 can be bypassed and the audio input signal applied directly to the inputs of the TPA005D02 class D EVM.

❑ Platform switch **S2** selects signal conditioning or bypasses it.

3.3.3.2 Headphone Output Jack

Switch S3 is the source select for the stereo headphone output jack, J10. The headphone jack is capacitively coupled (via 470 µF electrolytics) and can output either the signal from the headphone amplifier in socket U5, or the signal from the power amplifier installed in socket U2, as determined by the setting of headphone source select switch S3.

❑ The TPA005D02 is designed to drive BTL loads only, **S3 MUST ALWAYS BE SET TO THE *U5* POSITION** when the TPA005D02 class D EVM is installed on the platform.

3.3.4 Mute

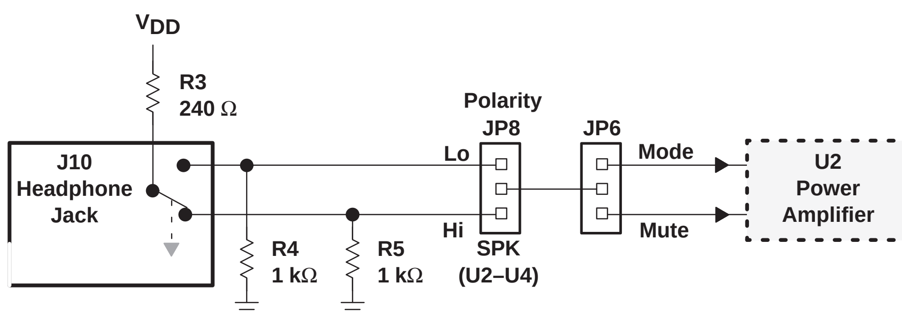
The TPA005D02 class D EVM is equipped with a mute control input pin. When this input is tied to GND, the TPA005D02 amplifier IC on the module enters the mute mode and dissipates very little power. When the EVM control input is tied to V_{DD} or allowed to float, amplifier operation resumes.

In typical applications, as often found in notebook computers, portable audio products, and such, the internal speakers mute when headphones are plugged into the headphone jack, or internal speakers mute when external speakers are connected. In applications using separate speaker and headphone amplifiers, the one not being used can be muted to conserve power.

3.3.4.1 Headphone Jack Control Signals

The platform headphone output jack (J10) contains an internal switch that changes the state of a pair of control lines when a plug is inserted (Figure 3–19). Each control line is pulled down by a 1-kΩ resistor to ground (R4 and R5). The switch in the headphone jack pulls one line or the other up to V_{DD} through a 240-Ω resistor (R3) depending on whether a plug is inserted in J10 or not.

Figure 3–19. Mute/Mode and Polarity Control



3.3.4.2 Mute/Mode Select (JP6)

A 3-pin jumper header (JP6) on the platform, functioning as an SPDT switch, routes the control signal from the headphone jack to either the mute control input pin or the mode control input pin of the evaluation module.

- To mute the TPA005D02 class D EVM using the control signal from the platform headphone jack, jumper **JP6** to ***MUTE.***
- To isolate the TPA005D02 class D EVM from the headphone jack switch (since the TPA005D02 class D EVM has no mode control input), jumper **JP6** to ***MODE.***

3.3.4.3 Mute/Mode Polarity Select (JP8)

A second 3-pin jumper header (JP8) on the platform selects the control signal polarity by connecting either the active-high or the active-low line from the headphone jack to jumper JP6.

- ❑ To mute the TPA005D02 class D EVM *when* a plug is inserted into the headphone jack, jumper **JP8** to ***Lo*** (the ***Hi*** position is **NOT** recommended).

3.3.5 Power Requirements

The TPA005D02 Class D Stereo Audio Power Amplifier Evaluation Module is designed to operate from a supply voltage between 4.5 V and 5.5 V. For best performance (highest output power with lowest distortion), the module should be operated on at least 5 V.

The TI Plug-N-Play Audio Amplifier Evaluation Platform with a voltage regulator EVM installed on it can provide a regulated V_{DD} supply from a wide variety of unregulated V_{CC} voltage inputs between approximately 5.5 V and 12 V, including an onboard 9-V battery. Or, an external regulated power source can be used to supply V_{DD} voltage to the platform and the TPA005D02 evaluation module installed on it.

Although the TPA005D02 amplifier IC draws approximately 2 A from the power supply during continuous full power output, peak current draw can be as high as 5 A. Any power supply connected to the platform should be capable of providing 5 A of current to avoid clipping of the output signal during peaks. Current consumption driving speakers at normal listening levels is typically 0.5 A or less.

The platform is equipped with overvoltage and reverse-polarity supply voltage input protection in the form of fused crowbar circuits.

- ❑ V_{DD} voltage applied to platform screw terminals J6 ***MUST NOT*** exceed the absolute maximum rating for the TPA005D02 amplifier IC installed on the evaluation module (5.5 V) or damage to the IC may result. In no case should V_{DD} voltage of the incorrect polarity or in excess of 6.1 V be applied to screw terminals J6 of the platform, or the power protection circuit on the V_{DD} line will trip.

- ❑ V_{CC} voltage applied to the platform ***MUST NOT*** exceed the maximum voltage input specified for the voltage regulator module installed in socket U6 (12 V for the SLVP097), or damage to the voltage regulator module may result. In no case should V_{CC} voltage applied to the platform exceed 15 V, or the overvoltage protection circuit on the V_{CC} bus will trip.

3.3.6 Inputs and Outputs

The TI Plug-N-Play Audio Amplifier Evaluation Platform is equipped with several standard conectors for audio inputs and outputs.

3.3.6.1 Inputs

In most cases, audio signals enter the platform through either a pair of RCA phono jacks (J3 and J5) or a miniature (1/8″) stereo phone jack (J4). Certain signal conditioning and amplifier EVMs, however, may have additional signal input connectors mounted on the module circuit board.

The platform audio signal input jacks (J3, J4, and J5) are of the closed-circuit type, grounding the signal input lines when no plugs are inserted.

3.3.6.2 Outputs

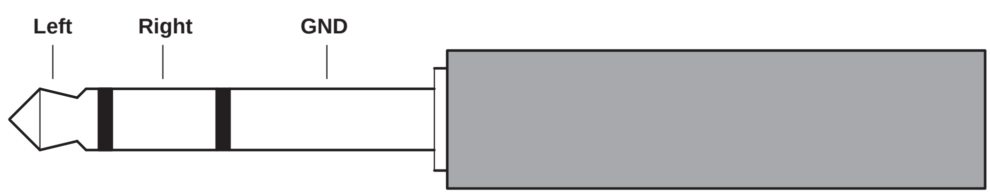
Amplified audio output signals leave the platform through left and right RCA phono jacks (J7 and J9), left and right pairs of compression connectors for stripped speaker wires (J8), and optionally, through a miniature (1/8″) stereo phone jack (J10), for headphones.

The audio output lines from the power amplifiers are separate all the way to the edge of the platform (output jacks J7, J8, and J9)—the OUT– lines from the power amplifier sockets are not tied to each other or to platform ground. This allows the TPA005D02 power amplifier EVM to operate in the highly-efficient bridge-tied load configuration when driving speakers.

The headphone jack (J10) is capacitively coupled to source select switch S3, which connects J10 to the output lines of either the headphone amplifier socket or the power amplifier sockets (Figure 3–20). Since the TPA005D02 class D EVM can drive only BTL outputs, **S3 MUST ALWAYS BE SET TO THE *U5* POSITION**.

Do not drive the module inputs unless speaker loads are connected to the module outputs or the TPA005D02 amplifier IC will go into thermal shutdown.

Figure 3–20. Typical Headphone Plug



3.4 Using The TPA005D02 Class D EVM Stand-Alone

Using the TPA005D02 Class D Stereo Audio Power Amplifier Evaluation Module stand-alone is much the same as using it with the platform. The same 4.5-V to 5.5-V power supply range and the isolated OUT+ and OUT– lines for BTL operation requirement exists.

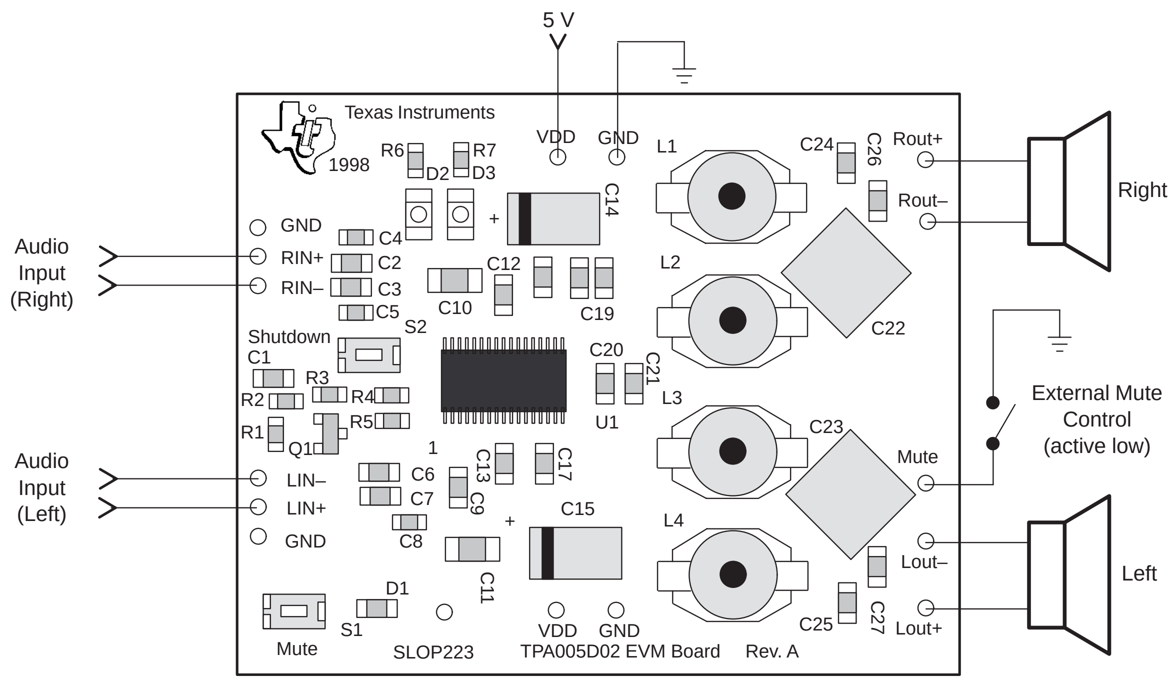
Power can be connected to either V_{DD} pin on the module. The audio input signal should be connected to the RIN+/RIN– and LIN+/LIN– module pins for differential signals as shown below. Single-ended input signals are applied to RIN+ and LIN+, while RIN– and LIN– are connected to ground.

Note that the mute signal applied to the EVM mute pin must be able to supply enough current to overcome the pullup resistor on the module (100 kΩ).

Do not drive the module inputs unless speaker loads are connected to the module outputs or the TPA005D02 amplifier IC will go into thermal shutdown.

3.4.1 TPA005D02 Class D EVM Connected for BTL Output

Figure 3–21. TPA005D02 Class D EVM Connected for Stereo BTL Output



3.5 TPA005D02 Audio Power Amplifier Evaluation Module Parts List

Table 3–3. TPA005D02 Class D EVM Parts List

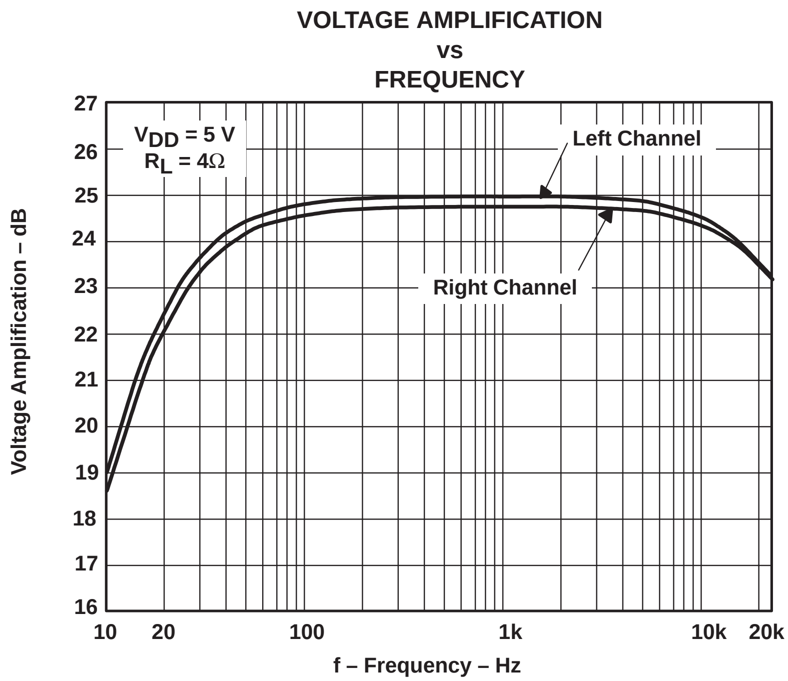
Reference	Description	Size	EVM Qty.	Manufacturer/ Part Number
C1, C2, C3, C6 C7, C9, C12, C13, C16, C17, C18, C19	Capacitor, Ceramic, 1 µF, 16 V, Y5V, +80% –20%	0805	12	muRata GRM40Y5V105Z16
C4, C5, C8	Capacitor, Ceramic, 470 pF, 50 V, X7R, 10%	0603	3	muRata GRM39X7R471K50
C20, C21	Capacitor, Ceramic, 0.047 µF, 50 V, X7R, 10%	0805	2	muRata GRM40X7R473K50
C10, C11	Capacitor, Ceramic, 10 µF, 16 V, Y5V, +80%–20%	1210	2	muRata GRM235Y5V106Z16
C14, C15	Capacitor,Tantalum, 220 µF, 10 V, 20%	Case E	2	AVX TPSE227M010
C24, C25, C26, C27	Capacitor, Ceramic, 0.22 µF, 25 V, X7R, 10%	0603	4	muRata GRM39X7R224K10
C22, C23	Capacitor, Metal Film, 1 µF, 50 V, ±5%, leaded	0.287 × 0.315 × 0.197	2	Panasonic ECQ-V1H105JI
D2, D3	LED, SM, Green, 25 mcd, 2.1 V, 120 deg	0.134 × 0.11 × 0.071	2	Lumex SML-LX2832GC-TR
L1, L2, L3, L4	Inductor, 15 µH, 3.1 A rms, 0.060 Ω	0.51 × 0.37 × 0.30	4	Coilcraft DO3316P-153
Q1	Transistor, PNP, 60 V, 200 mA	SOT-23	1	Zetex FMMT3906CT-ND
R1, R3	Resistor, SMD, MF, 20 kΩ, 1/16 W, 5%	0603	2	Vishay/Dale CRCW0603203J
R2, R6, R7	Resistor, SMD, MF, 1 kΩ, 1/16 W, 5%	0603	3	Vishay/Dale CRCW0603102J
R4, R5	Resistor, SMD, MF, 100 kΩ, 1/16 W, 5%	0603	2	Vishay/Dale CRCW0603104J
S1, S2	Switch, Momentary, PB, 12 VDC, 50 mA	0.291 × 0.138 × 0.134	2	Panasonic EVQ-PJS04K
U1	IC, Audio amplifier, class D, 5 W, 48 pin, DCA pkg	TSSOP48	1	TI TPA005D02DCA
D1	Diode, Zener, SMT, 3.9 V, 500 mW, 50 µA, 1N4686	SOD-123	1	Motorola MMSZ4686T1

3.6 TPA005D02 Class D EVM Measured Characteristics

The TPA005D02 Class D Stereo Audio Power Amplifier EVM was tested using an Audio Precision 2322, a 5-V regulated DC power supply, the TI PNP Audio Power Amplifier Evaluation Platform set up as described in Chapter 2, and 4-W speaker loads. The results are shown in Figures 3–22 through 3–25. The TPA005D02 class D EVM exhibits slightly less harmonic distortion at high power levels when used in the stand-alone mode.

The EVM has a flat response over the audio frequency band, as shown in Figure 3–22. Both channels track closely; however, the response will change slightly with the tolerance of the filter components. The lower and upper frequency corners can be adjusted to extend frequency response as described in sections 3.2.3.1 and 3.2.3.2.

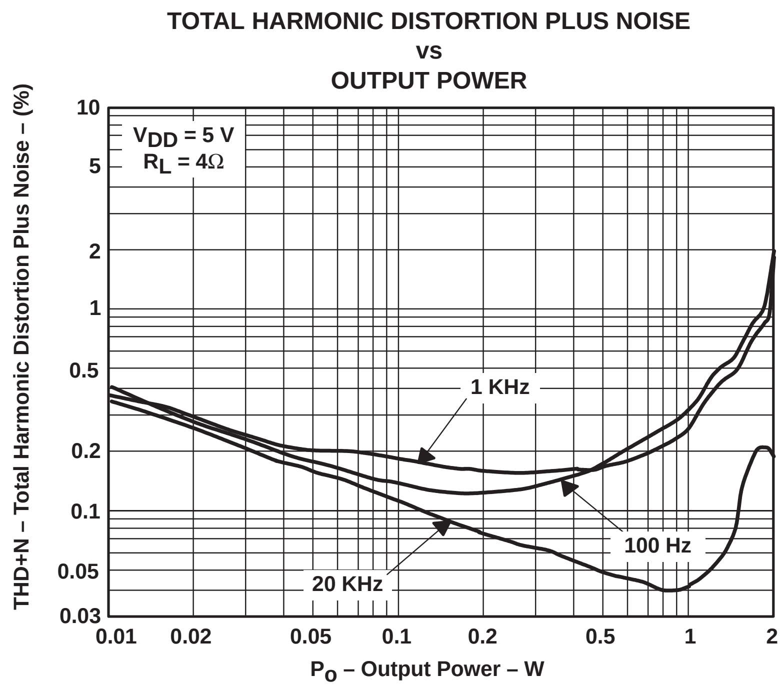
Figure 3–22. Frequency Response



Total harmonic distortion plus noise (THD+N) versus output power is shown in Figure 3–23. A lower power levels (less than 40 mW), most of the distortion is contributed by the class D amplifier device. Distortion at mid and high power levels (40 mW to 1.9 W) is a function of the output filter components, particularly the inductors.

A slight increase in supply voltage over 5 V substantially reduces the harmonic distortion at power levels above 500 mW.

Figure 3–23. Distortion versus Output Power



THD+N versus frequency is shown in Figure 3–24, and correlates with the data shown in Figure 3–23. The rise in distortion at higher frequencies is due primarily to the increase in crosstalk with frequency (Figure 3–25). The crosstalk was measured at full output power, which is the worst-case scenario. Crosstalk may be reduced by using shielded inductors in the output filter.

Figure 3–24. Distortion versus Frequency

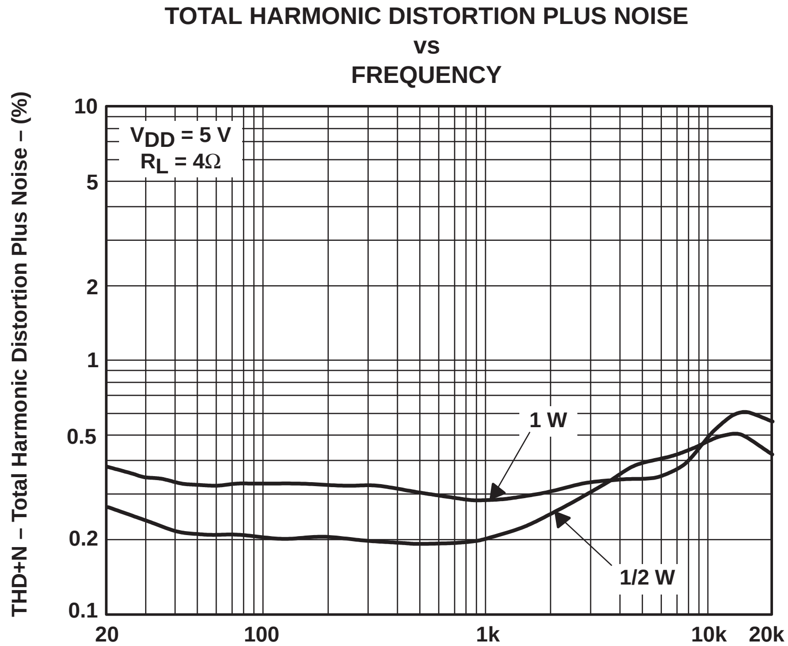
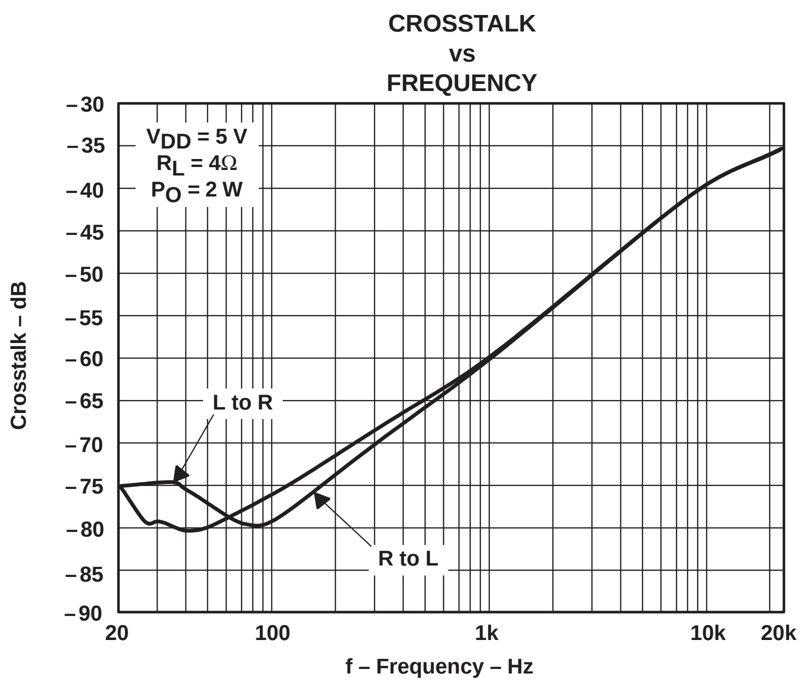


Figure 3–25. Crosstalk versus Frequency



3.7 TPA005D02 Class D EVM PCB Layers

The following illustrations depict the TPA005D02 class D EVM PCB layers. These drawings are not to scale. Gerber plots can be obtained from any TI Sales Office.

Figure 3–26. TPA005D02 Class D EVM Silkscreen

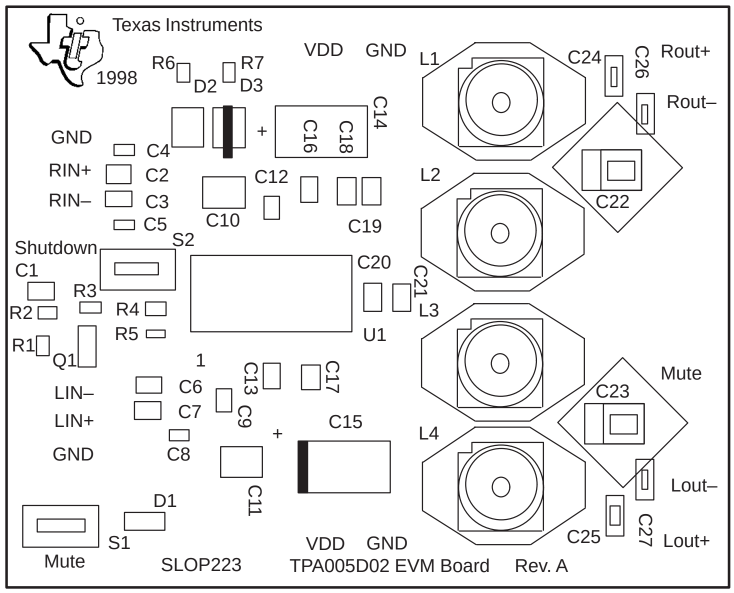


Figure 3–27. TPA005D02 Class D EVM Top Layer

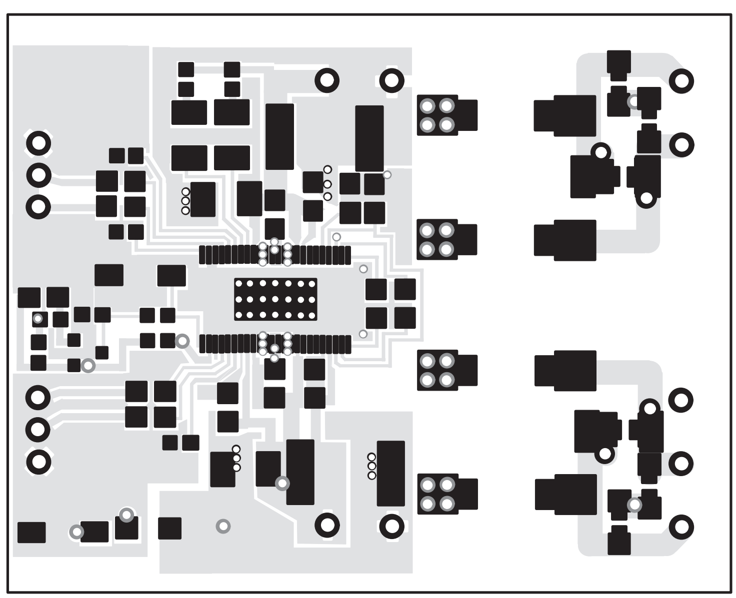


Figure 3–28. TPA005D02 Class D EVM 2nd Layer

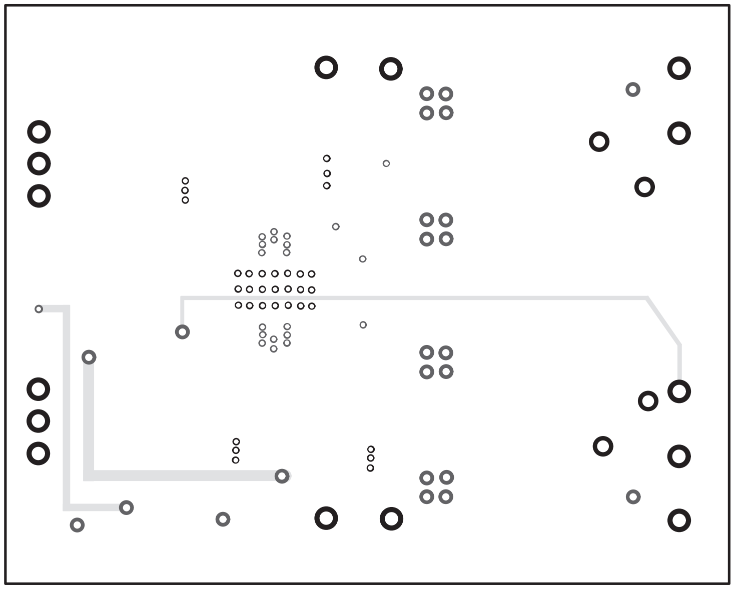


Figure 3–29. TPA005D02 Class D EVM 3rd Layer

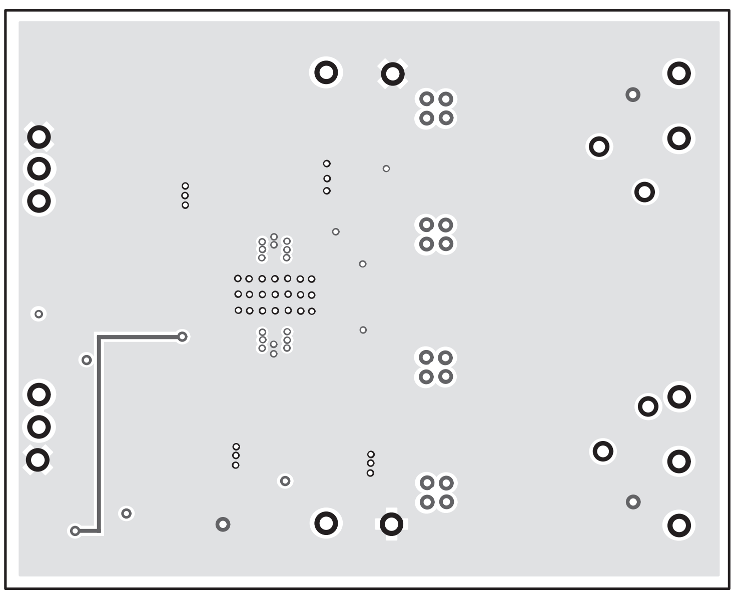


Figure 3–30. TPA005D02 Class D EVM Bottom Layer