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Thermal design considerations for TAS5805M Class-D audio amplifier

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ABSTRACT

The TAS5805M is a high-efficiency, stereo, closed-loop Class-D audio amplifier that can be used in many applications such as Smart Speakers, televisions, and so forth. In some real use cases, there are still thermal problems in large-output power situations if the design is not carefully considered. Proper parameter selection is critical to meet the desired thermal performance in the customer's applications. This application report discusses some key factors to be considered in the TAS5805M thermal design, such as switching frequency, modulation modes, and PCB layout.

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1 Class-D Audio Amplifier Overview

Figure 1 shows the Class-D audio amplifier. This amplifier is a switching amplifier that consists of a pulse width modulator, a power stage, and an output filter. The output of a Class-D amplifier is a PWM (pulse-width-modulation) switched signal with duty cycle that is modulated with audio signal. Compared with traditional Class-AB audio amplifier, the efficiency of the Class-D amplifier has been significantly improved. In some real cases, Class-D audio amplifiers still have thermal problems when the design is not good enough. The thermal performance is mainly influenced by power losses and heat dissipation.

To achieve better thermal performance, the power losses in the Class-D audio amplifier power stage must be taken into consideration since the Class-D audio amplifier efficiency is related to MOSFET total power losses. These power losses are the results of MOSFET conduction, switching, and gate charge losses. Power loss is mainly correlated with efficiency. Generally speaking, the efficiency of a Class-D audio amplifier is mainly influenced by the output filter and its ripple current, switching frequency, and power loss from the power stage.

Heat dissipation is mainly affected by PCB layout. PCB contributes up to 80-90% of heat dissipation for thermally attached devices. The tips of PCB layout for TAS5805M is discussed in this application report.

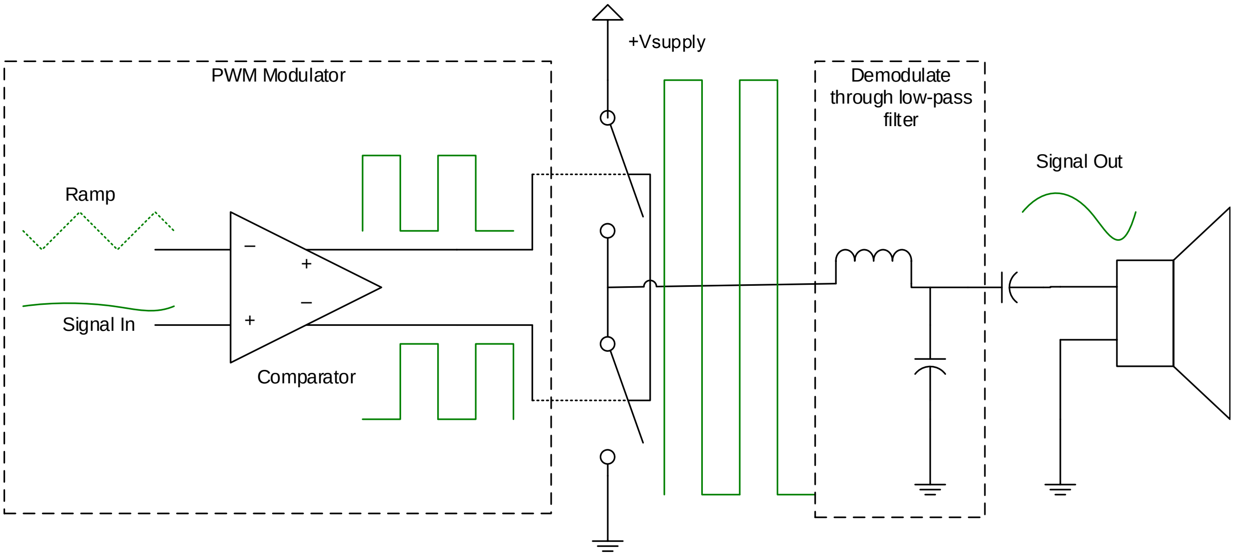

Figure 1. Typical Block Diagram of Class-D Audio Amplifier

This report uses TAS5805M as an example to discuss thermal design considerations in Class-D audio amplifiers. The report analyzes the thermal problems in TAS5805M from two aspects: power losses and heat dissipation. To reduce power losses, some factors need to be taken into account, such as switching frequency, modulation mode, and output filter selection of TAS5805M. Thermal performance is also related to heat dissipation. For better thermal performance, the PCB layout must be designed properly to minimize the thermal impedance and achieve the best balance of thermal and electrical electromagnetic performance.

2 Power Losses Considerations in Class-D Audio Amplifier

2.1 PWM Control Scheme Considerations

The Class-D audio amplifier is a switching amplifier that consists of a pulse width modulator. When talking about PWM control scheme in TAS5805M, there are two main factors to be considered:

- PWM switching frequency
- Modulation mode

Different selections of switching frequency and modulation mode influences MOSFET power losses and ripple current flowing through LC filter. Large inductor ripple current causes power losses in inductor DCR and decreases efficiency accordingly.

2.2 PWM Switching Frequency Selection

In the Class-D audio amplifier, PWM switching frequency mainly influences the MOSFET losses and inductor losses. To achieve higher efficiency, MOSFET losses must be taken into consideration. MOSFET-related power loss is composed of conduction loss, switching loss, and gate-drive loss. The conduction loss is mainly related to R_{dson} of the MOSFET in the Class D audio amplifier. The conduction loss is independent with switching frequency, but switching loss and gate-drive loss increase linearly with increasing switching frequency. It takes a finite amount of time for the MOSFET to turn on and off. Figure 2 shows that the switching loss comes from the dynamic voltages and currents, which the MOSFETs must handle during the time it takes to turn on or off. Equation 1 shows that the MOSFET switching losses are a function of load current, power supply, and switching frequency.

$$P_{SW} = V_{IN} \times I_{OUT} \times f_{SW} \times \frac{\left(Q_{GS2} + Q_{GD}\right)}{I} \tag{1}$$

Where V_{IN} = V_{DS} (drain-to-source voltage), I_{OUT} = I_D (drain current), fsw is the switching frequency, Q_{GS2} and Q_{GD} depend on the time the driver takes to charge the MOSFET, and I is the gate current

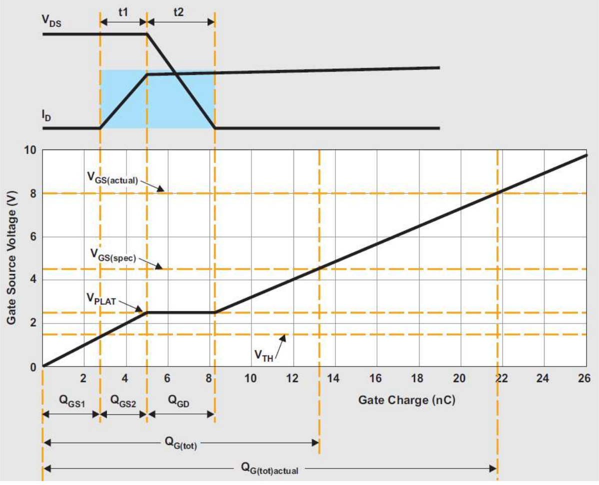

Figure 2. Explanation for MOSFET Switching Loss

Figure 3 shows that the MOSFET gate losses are caused by the energy required to charge and discharge the MOSFET gate. These are both turn-on and turn-off gate losses. Equation 2 shows that the gate drive losses are frequency dependent and are also a function of the gate capacitance of the MOSFETs. When turning the MOSFET on and off, the higher the switching frequency, the higher the gate-drive losses. Gate-drive losses are another reason why efficiency decreases as the switching frequency increases.

$$P_{gate} = V_{GS} \times f_{SW} \times Q_{G(TOT)} \tag{2}$$

Where the $Q_{G(TOT)}$ is the turn-on and turn-off gate losses. V_{GS} is the drain-to-source voltage.

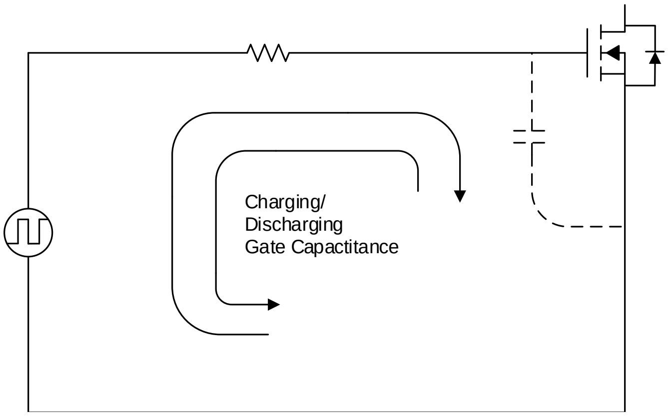

Figure 3. Explanation for MOSFET Gate Loss

Besides the MOSFET losses, the switching frequency also influences the ripple current flow through the post LC filter. The ripple current causes power losses in the inductor. Higher switching frequency means you need a smaller inductor value and a lower ripple current in the inductor. Switching frequency both influences ripple losses and MOSFET losses. When talking about power losses, consider which is the major factor in the current situation, the MOSFET losses or the ripple current.

At free-air room temperature 25°C, the following measurements are made using TAS5805M EVM board. Output power is measured by Audio Precision. All measurements are taken with PVDD = 16 V, speaker load = 6 Ω. The device PWM frequency is set to 384 kHz and 768 kHz, respectively, in BD Modulation. Spread Spectrum is enabled. The output filter is configured as LC filter (10 µH+0.68 µF). Figure 4 shows the test results.

Figure 4 shows that when output power is greater than about 14 W, the efficiency of 384 kHz is higher than 768 kHz. When output power is small, the power losses are mainly dominated by ripple current as 768 kHz switching frequency has smaller ripple current than 384 kHz, and the efficiency are higher too. When output power is large, the power losses are mainly dominated by MOSFET losses, and switching losses are smaller with lower switching frequency.

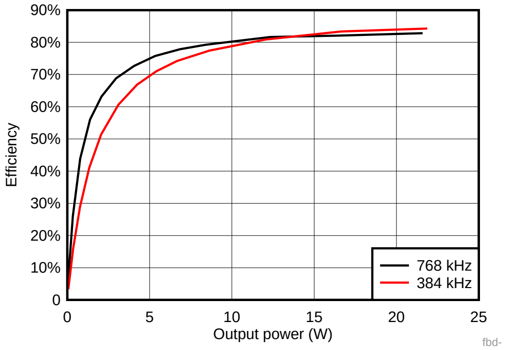

Figure 4. Efficiency vs. Output Power in Different Switching Frequency (BD Mode)

2.3 Modulation Mode Selection

Different modulation modes also influence Class-D audio amplifier efficiency. TAS5805M has three different modulation modes:

- BD modulation
- 1SPW modulation
- Hybrid modulation

In BD mode, Class-D audio amplifiers produce a common-mode voltage of PVDD/2 after the L-C filter at idle status, which is the average value of the 50% duty-cycle PWM switching waveform in the BTL, as shown in Figure 5. The maximum voltage across the inductor is PVDD / 2 and the minimum voltage is minus PVDD / 2. Figure 6 shows the inductor voltage and current waveforms. In traditional Class-D audio amplifiers, it is typically necessary to pass the modulated PWM signal through a low pass filter to extract the audio content. The low pass filter generally consists of a series inductor and a capacitor to ground. In traditional Class-D audio amplifiers the positive (OUT+) and the negative (OUT–) outputs are always out of phase, with 50% duty cycle when no input signal is applied. As a result, the full output voltage is applied to the load at all times, producing relatively high current and high power dissipation in the load if no filter is used.

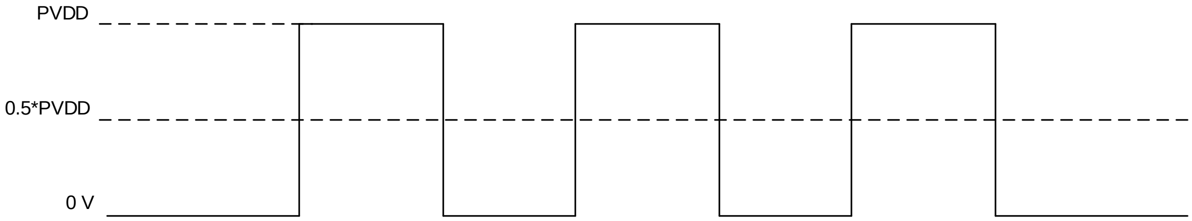

Figure 5. PWM Voltage Waveform (50% Duty-Cycle)

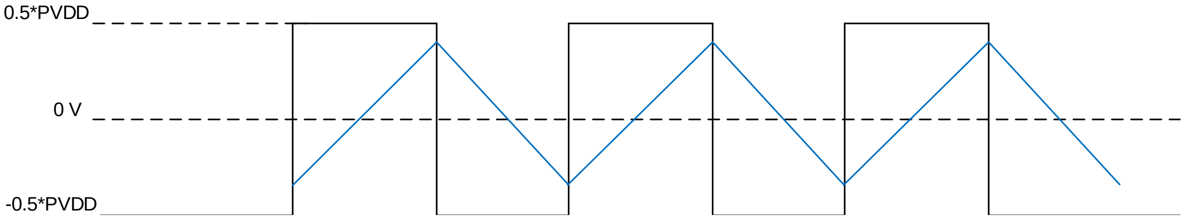

Figure 6. PWM Voltage Waveform (50% Duty-Cycle)

Use Equation 3, Equation 4, and Equation 5 to find the peak ripple current in BD mode at idle status.

$$I_{peak\_current} = \frac{PVDD/2}{L}\delta t \tag{3}$$

$$I_{peak\_current} = \frac{PVDD/2}{L} \times \frac{1}{4 \times f_{SW}} \tag{4}$$

$$I_{peak\_current} = \frac{PVDD}{8 \times L \times f_{SW}} \tag{5}$$

The 1SPW mode alters the BD modulation scheme in order to achieve higher efficiency with a slight defect in THD+N. In Low Idle Current mode, the outputs operate at approximately 17% modulation during idle conditions. When an audio signal is applied, one output decreases and one increases. The decreasing output signal quickly rails to ground. The result is that only one output is switching during a majority of the audio cycle. Efficiency is improved in this mode due to the reduction of switching losses. The duty-cycle is lower in 1SPW mode than in BD mode. For example, if you use the 15% duty-cycle, the common-mode voltage after the LC filter is 0.15 × PVDD, as shown in Figure 7. Figure 8 shows the maximum voltage across the inductor is 0.85 × PVDD and the minimum voltage is –0.15 × PVDD.

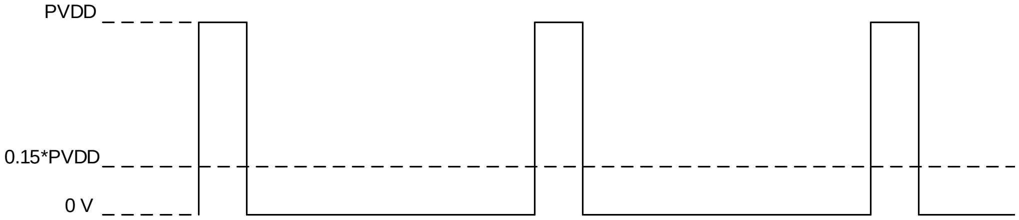

Figure 7. PWM Voltage Waveform (50% Duty-Cycle)

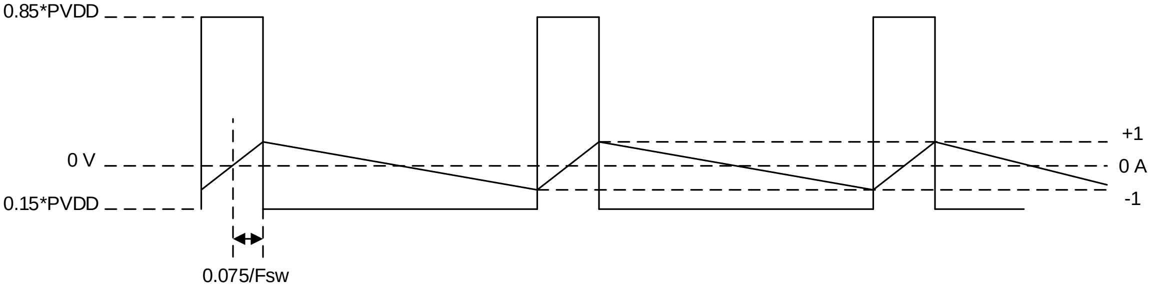

Figure 8. PWM Voltage Waveform (50% Duty-Cycle)

Use Equation 6, Equation 7, and Equation 8to find the peak ripple current in 1SPW mode at idle.

$$I_{peak\_current} = \frac{0.85 \times PVDD}{L} \delta t \tag{6}$$

$$I_{peak\_current} = \frac{0.85 \times PVDD}{L} \times 0.075 \frac{1}{f_{SW}} \tag{7}$$

$$I_{peak\_current} = \frac{51}{800} \frac{PVDD}{L \times f_{SW}} \tag{8}$$

The 1SPW mode has lower ripple current on the inductors than BD mode and makes higher efficiency. Figure 9 shows one of the OUTP and OUTN stops switching during large output condition in 1SPW mode. The result is that only one output is switching during a majority of the audio cycle. Efficiency is also improved in this mode due to the reduction of switching losses.

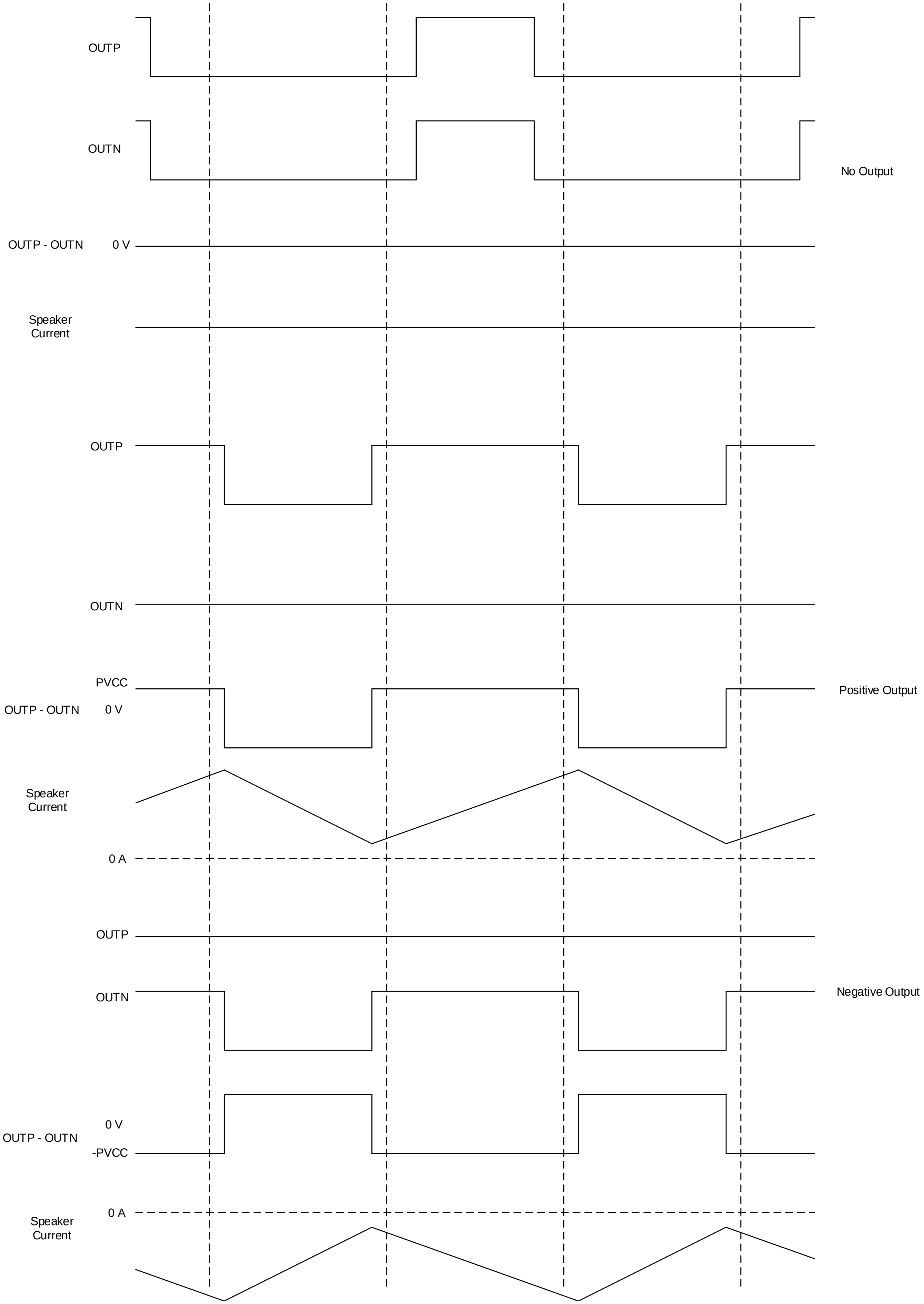

Figure 9. 1SPW Mode in Large Output Condition

Figure 10 compares the efficiency of different modulation mode. The result is tested with LC filter (10 µH + 0.68 µF) and the switching frequency is 768 kHz. The 1SPW mode has lower ripple current on the inductors than BD mode in idle condition and makes higher efficiency. Only one output is switching during the majority of the audio cycle in a large output condition, therefore, it can also improve the efficiency.

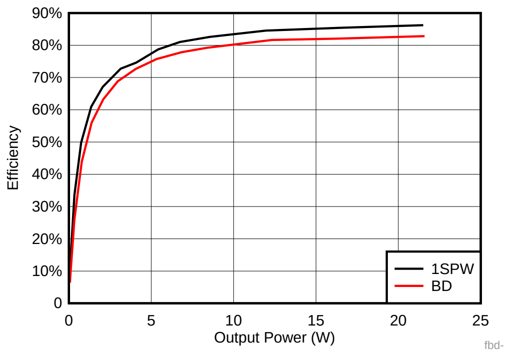

Figure 10. Efficiency vs. Output Power with Different Modulation Mode (Fsw = 768 kHz)

Figure 11 shows PVDD, which is an important factor for thermal design. The efficiency of TAS5805M decreases with the increase of PVDD. When PVDD > 19 V, use 1SPW rather than BD, considering the efficiency. In summary, the efficiency of 1SPW is higher than BD mode and it is suggested you choose 1SPW mode in large output condition. In addition, a larger load means better efficiency.

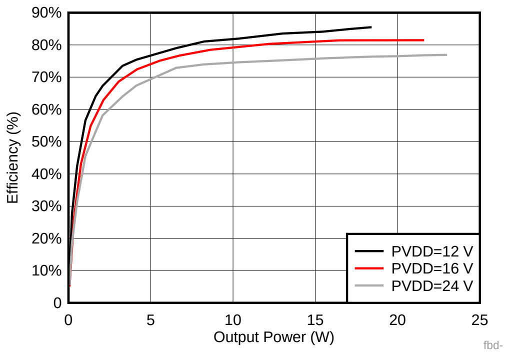

Figure 11. Efficiency vs. Output Power with Different PVDD (1SPW Mode)

2.4 Output Filter Selection

Switching outputs of Class-D audio amplifiers produce harmonics that extend to several hundred MHz, but the Federal Communications Commission (FCC) has imposed limits on radiated emissions at frequencies between 30 MHz and 1 GHz. It is necessary to filter a Class-D amplifier output to comply with Electro Magnetic Compliance, or EMC. Ferrite beads and LC filter can be used to meet the FCC limits in the TAS5805M. In many cases, ferrite bead filters can attenuate the high frequencies in the output of Class-D audio amplifiers, but ferrite beads have little effect on lower frequency signals. The load has the full PWM signal across its terminals, causing a high-frequency current to pass through the load, which leads to high power dissipation and thermal problem. To meet the FCC limits and reduce power dissipation, it is highly recommended to choose lower switching frequency (384 kHz) and BD mode in ferrite bead cases.

In LC filter cases, speaker impedance includes inductance, but it is primarily resistive, whereas an LC filter is almost purely reactive. An LC filter with a cutoff frequency less than the Class-D switching frequency allows the switching current to flow in the filter instead of the load. The filter has less resistance but higher impedance at the switching frequency than the speaker, resulting in less power dissipation, therefore increasing efficiency.

Ripple current is defined as the alternating current flowing through the output inductor of a Class-D amplifier. If LC filter is not designed properly, it also causes a large current to pass through the load, which leads to high power dissipation, poor efficiency, and potential speaker damage. High power dissipation causes thermal problems. In a BTL configuration, the total power dissipation due to the ripple current must be considered for both sides of the output bridge. The ripple current through an inductor is defined as:

$$\frac{di}{dt} = \frac{V}{L}$$

where

- di /dt = rate of change in inductor current
- V = voltage across the inductor
- L = inductance (9)

Equation 9 shows that the larger value inductors in the output filter make lower ripple current. Lower ripple current is desired in BD modulation amplifiers to reduce loss across the RDS (of the output FETs and the DCR of the output inductors on). Inductor DCR is the series electrical resistance of the wire used to make the windings in an inductor. Although the DCR is usually low, at high output current, the DCR can contribute considerable power losses for the audio signal. In 384 kHz switching frequency, it is recommended that choose at least 10 µH inductor in LC filter. See the *LC Filter Design application report* for details. Increasing the inductance reduces the output ripple current, and better efficiency is generally observed. With 384 kHz switching frequency, select 22 µH + 0.68 µF or 15 µH + 0.68 µF or 10 µH + 0.68 µF as the output filter (Speaker Load = 8 Ω/6 Ω), this helps reduce power dissipation. When choosing 768 kHz as the TAS5805M switching frequency, you can choose a smaller inductor value during the inductor selection. It is highly recommended to select 10 µH + 0.68 µF or 4.7 µH +0.68 µF as the output filter.

The output filter also influences the efficiency of TAS5805M, as shown in Figure 12. The TAS5805M is set to 384 kHz and BD mode. Ferrite beads cause a high-frequency current to pass through the load, which leads to high power dissipation and thermal problem. An LC filter allows the switching current to flow in the filter instead of the load and has better thermal performance. To achieve better thermal performance, it is highly recommended that use LC filter as output filter when the output power is larger than $2^{10\ \mathrm{W}}$. Ferrite beads are often used in portable device with small output power.

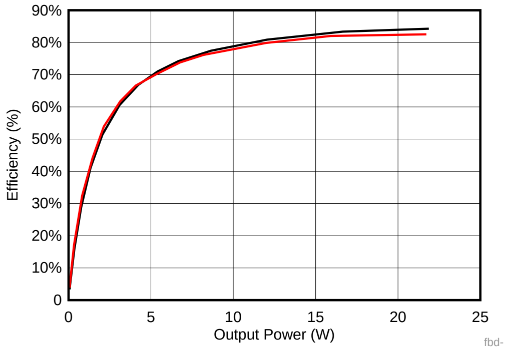

Figure 12. Efficiency vs. Output Power with Different Output Filter (BD mode, Fsw = 384 kHz)

3 PCB Layout Considerations

Compared with Class-AB audio amplifier, the efficiency of the Class-D amplifier has significantly improved. When the output power of Class D audio amplifier is large, there can be a thermal problem in certain circumstances. Device performance can be affected by high temperature, so it is important to understand and control the temperature during operation. The goal of the PCB design is to minimize the thermal impedance. The following tips must be followed to achieve better thermal performance:

- Avoid placing other heat producing components or structures near the amplifier.
- If possible, use a higher layer count PCB to provide more heat sinking capability for the device.
- Thickness of copper and layers of PCB have great effect on thermal performance. For the EVM board, it is 4 layers and 2Oz copper.

Place the Class-D audio amplifier away from the edge of the PCB when possible to ensure that the heat can travel away from the device on all four sides. In a soldered PowerPAD™ device, the heat travels from the die, through the die attach, to the die pad, through the solder and into the PCB where it is dissipated into the air. Center the IC in the ground plane and ground the PowerPAD with thermal vias. Figure 13 shows you an example of the correct placement. The thermal vias creates low thermal resistance from the PowerPAD to the ground plane for best heat transfer. With the IC centered, all paths through PCB copper for heat have reasonably low thermal resistance and good thermal radiating area.

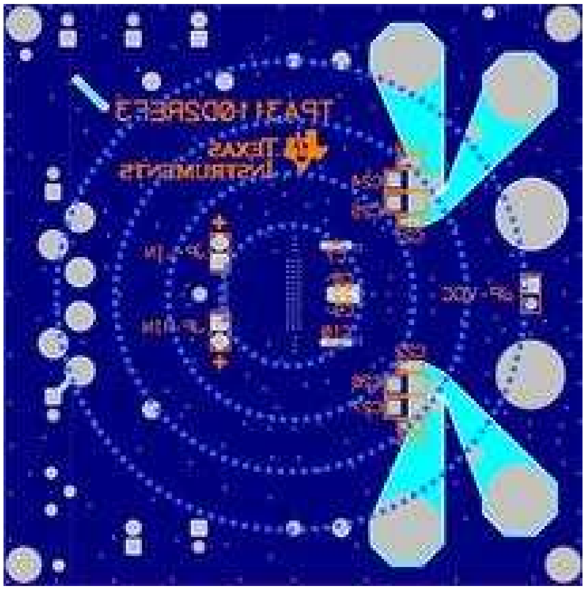

Figure 13. A Good Example of IC Placement

Avoid cutting off the flow of heat from the Class D audio amplifier to the surrounding areas with traces or strings. Radial or nearly radial cuts allow heat to flow, as shown in Figure 14. Radial or nearly radial cuts do not block paths for heat. They let heat flow between them, away from the IC. A circular cut disconnects the copper inside the cut from the copper outside the cut.

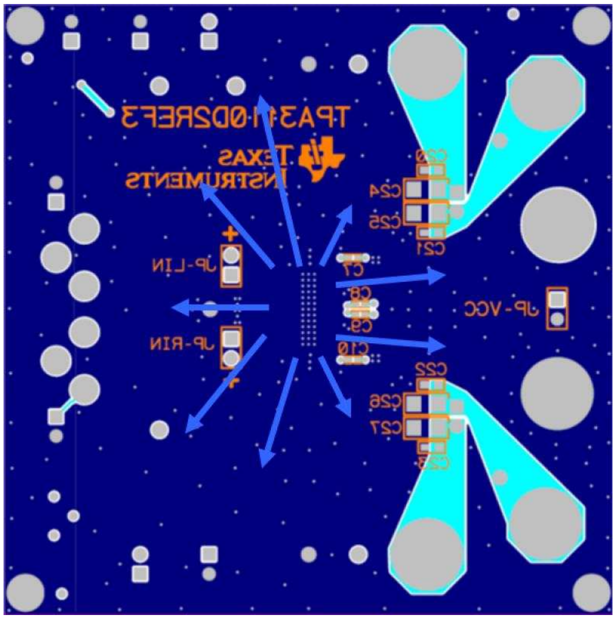

Figure 14. An Example of a Radial Cut

Heat flow to the copper outside the circular cut is reduced, so the copper outside cannot conduct much heat. A circular cut increases thermal resistance of the PCB and makes the IC run hotter, as shown in Figure 15.

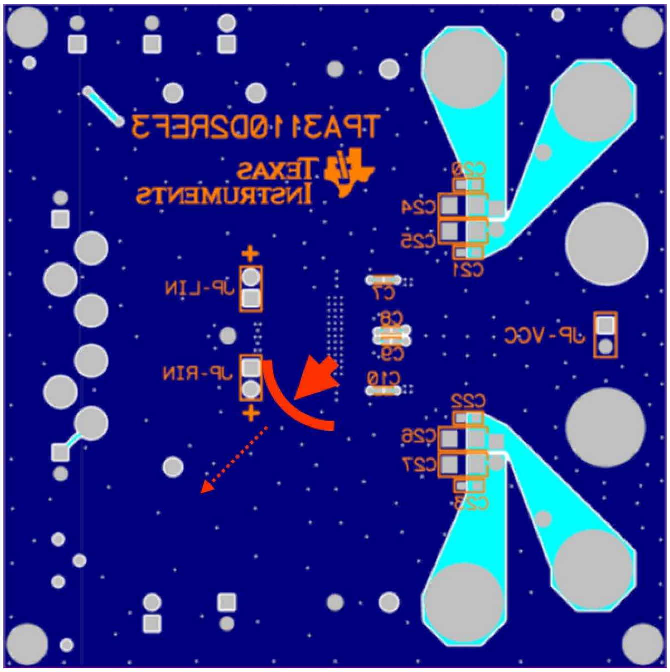

Figure 15. An Example of a Circular Cut

For the TAS5805M thermal pad, which connects electrically and thermally to the PowerPAD™ of the TAS5805M device, it is important that it is big enough for heat to pass. By increasing the number of vias, as shown in the Figure 16, we can improve thermal performance of the TAS5805M. The vias can carry the heat from the device through to the layers of the PCB. Vias is present a low thermal-impedance path from the device into the PCB. Then, the heat travels away from the device and into the surrounding structures and air. Vias must be arranged in columns, which extend in a line radially from the heat source to the surrounding area. Ensure that vias do not cut off power current flow from the power supply through the planes on internal layers. If needed, remove some vias that are farthest from the TAS5805M device to open up the current path to and from the device.

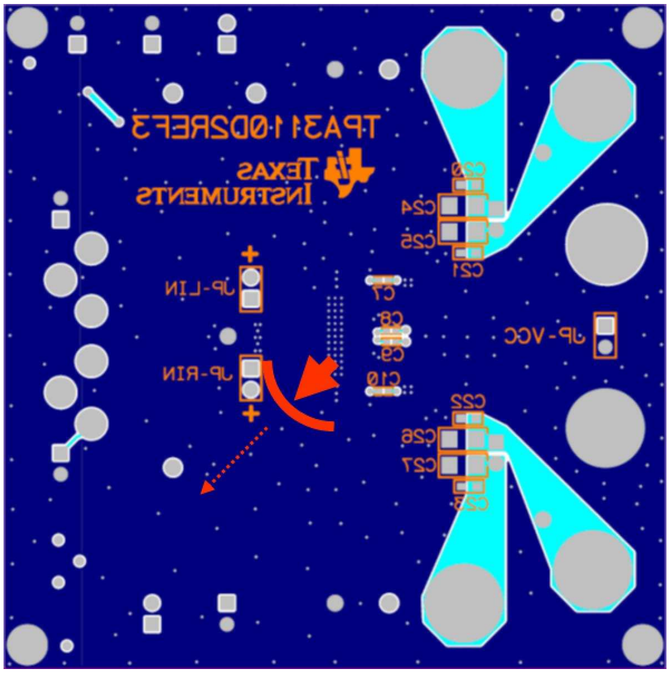

Figure 16. Layout Example of TAS5805M (Stereo BTL with Ferrite Bead)

4 Summary

The TAS5805M is a high-efficiency Class-D audio amplifier, but there are still thermal problems in large output power situations. The efficiency of a TAS5805M is mainly influenced by the output filter, switching frequency and PCB layout. Points to be remembered to achieve better thermal performance:

- In a Class-D audio amplifier, PWM switching frequency mainly influences the MOSFET losses and inductor losses. Lower PWM switching frequency with large inductor to improve thermal performance.
- LC filter can achieve better thermal performance than Ferrite Bead in large output situation.
- Place the TAS5805M device away from the edge of the PCB and avoid cutting off the flow of heat from the TAS5805M device to the surrounding areas with traces or via strings.

5 References

- *TAS5805M 23-W, Inductor-Less, Digital Input, Stereo, Closed-Loop Class-D Audio A data sheet*
- *Minimize Idle Current in Portable Audio With TAS5805M Hybrid Mode application report*
- *LC Filter Design application report*
- *Filter-Free™ Class-D Audio Amplifiers application report*

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