Application Report

Limitations of Capacitor Only EMI Filters on Class-D Amplifiers

ABSTRACT

Due to the fast switching response of many Class-D amplifiers, it is often necessary to include an output filter to meet guidelines and standards for radiated noise. Filter component selection is important since it will impact device performance and system efficiency. It is especially important to avoid the use of capacitor-only output filters when designing solutions with Class-D amplifiers to avoid inadvertently triggering built in device protection.

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1 Trademarks

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2 Introduction

The output from a Class-D amplifier consists of a PWM waveform that is typically resolved into a clean audio waveform by passing the signal through an LC filter to remove the high frequency portion of the output signal. Modern H-bridge amplifiers can operate without this filter by using the inductance to replace this filter. However, given the power levels typical to audio applications and the output switching frequencies required for this type of operation, a filter is often still necessary to meet electromagnetic emission standards. Many designers wish to use capacitive-only output filters given the small size and low cost required for these components, but this approach involves significant risk and it is not recommended for use on Class-D outputs.

3 Filter Design

One challenge commonly seen when introducting a filter to a PWM waveform is an increase in the noise floor of the signal. If the filter is not carefully designed, this can increase to levels easily detected by the end user. Generally, it is safe to set the filter corner frequency at or above 2x the effective maximum switching frequency with minimal impact to the noise floor. When designing for devices which utilize post filter feedback (TAS2560, TAS2557, and TAS2559) please refer to *Post FilterFeedback Class-D Amplifier Benefits and Design Considerations* application report.

3.1 Filter Cutoff Frequency Selection

When not utilizing post filter feedback, it is generally considered safe to set the filter corner frequency at or above 1.5 MHz. For example, TAS2770 outputs may each switch independently at 384 kHz. Additionally TAS2562,TAS2563, and TAS2564 all switch at this same output frequency. Depending on the alignment of these pulses we can see up to 768 kHz maximum effective switching frequency. If we double this frequency to ensure good signal fidelity we find a roughly calculated starting corner frequency near 1.5 MHz.

Depending on system design and overall component selection flexibility, it may be necessary to attempt setting the corner frequency below 1.5 MHz in order to meet emission requirements. It is possible to successfully design a filter below this frequency, but it may require iterative checks toevaluate noise emissions and overall device performance.

When considering a cutoff frequency below 1.5 MHz, the impedance of the filter at the Class-D switching frequency and at its first few multiples (harmonics) will be critical. If the filter does have a resonance at one of these frequencies, then it may draw higher currents. While the speaker itself will help to reduce peaking at this resonant point, we may still see enough energy to result in high frequency ringing. It is also noteworthy that the internally generated clock frequency may vary by +/-10%, which will widen the range of frequencies where care should be taken.

This ringing by itself will be outside the audio band and should not cause audible noise, but when voltage sense lines are connected to provide feedback to the device it may cause a few undesired effects. Ringing that peaks too high may cause the ESD protection diodes for the V sense pins to draw leakage current and it can cause internal filters to saturate and limit THD+N performance. Both of these are undersirable effects, but can mitigated by adding extra resistance of 1kOhm - 4.7 kOhms on the V sense path.

It is also helpful to reduce any high frequency ringing caused by the filter by carefully designing the filter Q-factor. High Q-factor responses will result with more ringing. When viewing a Bode plot of a filterresponse, we will expect to see more gain peaking around the cut-off frequency when the Q-factor is high. To aid with filter design, please download the LC Filter Calculator Tool.

An example of a known successful output filter on TAS2770 is shown below:

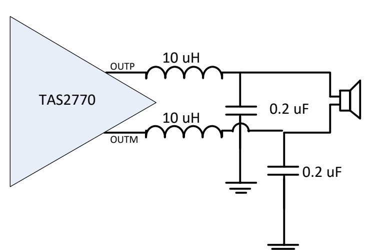

Figure 3-1. TAS2770 - 113-kHz Output Filter

It is useful to consider that the power supplied to the output will also be travelling along the battery supply line. Often, noise that appears related to output switching might actually be radiating from supply connections. Improved decoupling and proper supply design may help significantly reduce emissions without requiring aggressive filtering on the Class-D outputs.

3.2 Capacitance Only Filter Impact on Efficiency

The output filter will also introduce efficiency loss. When a square pulse is driven into to a capacitive path to ground, there will be a spike in leakage current during voltage transitions. The expected peak current can be calculated using the derivative form of the capacitor equation:

$$I = C \times (dV/dt) \quad (1)$$

During high dV/dt events, such as the rising or falling edge of a pulse we will observe significant current through the capacitor. Typical dV/dt rates for several common devices are shown in the following images.

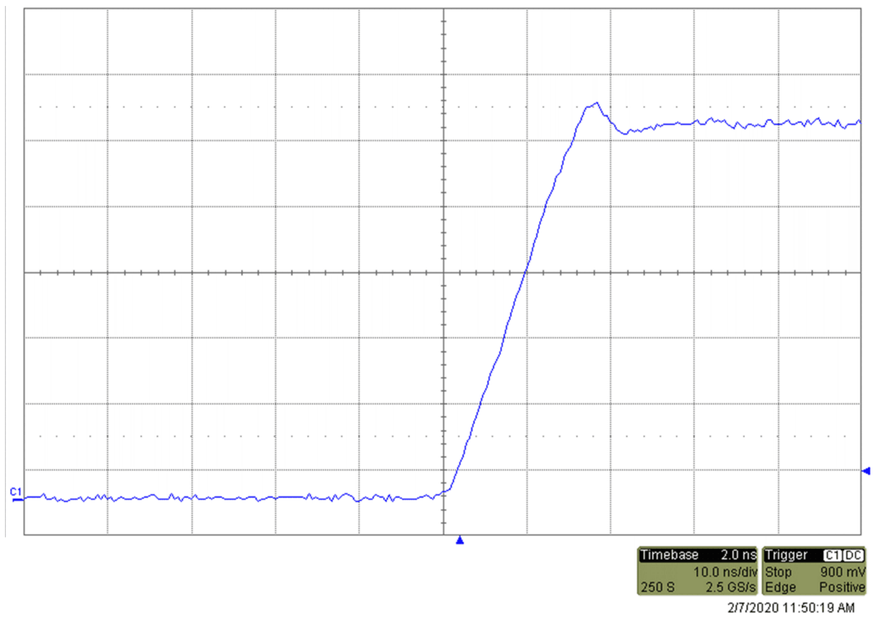

Figure 3-2. TAS2770: dV/dt = 2 V/ns

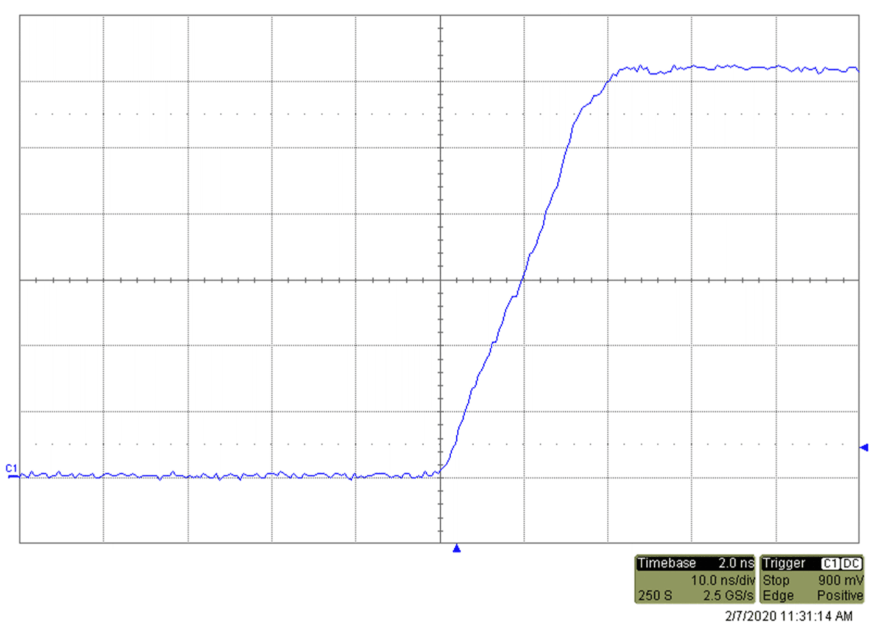

Figure 3-3. TAS2562: dV/dt = 0.7 V/ns

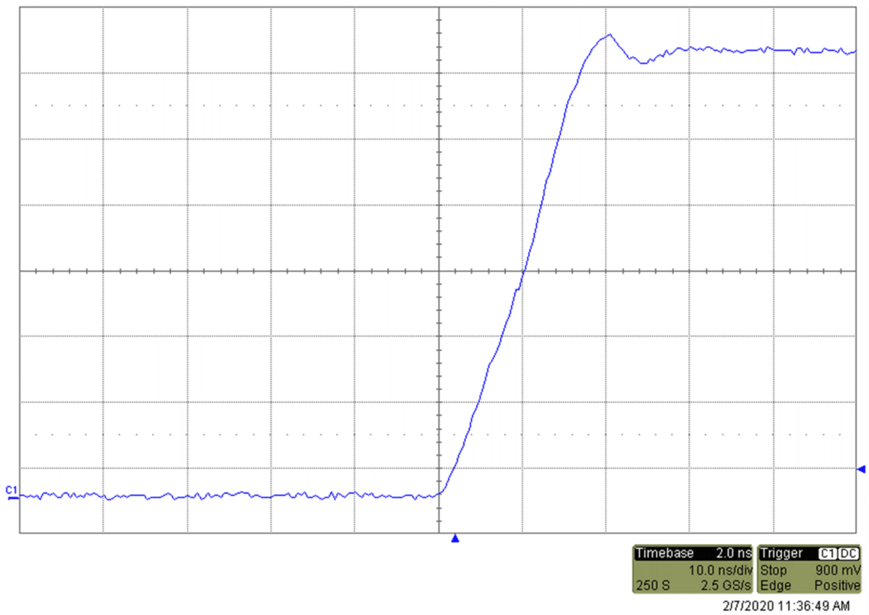

Figure 3-4. TAS2563: dV/dt = 0.7 V/ns

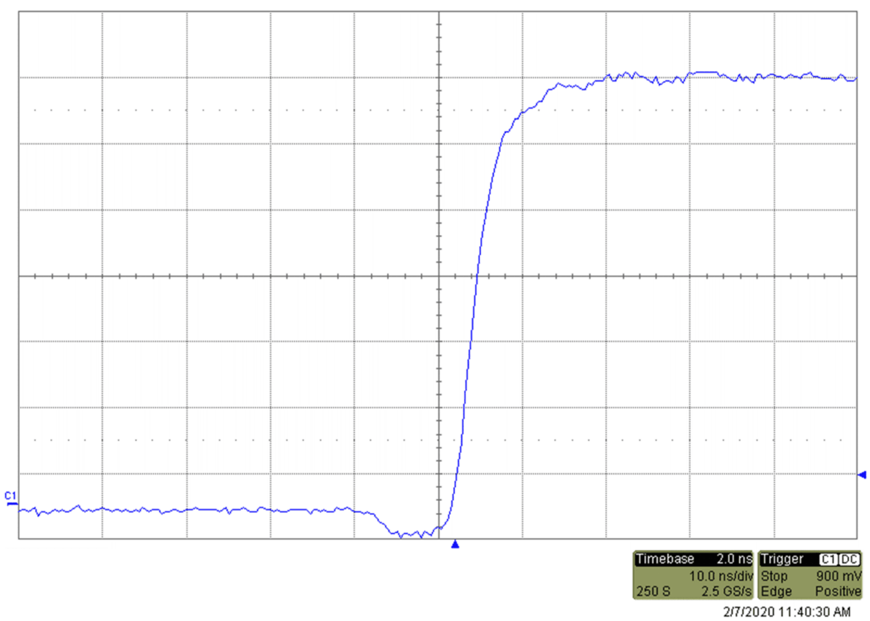

Figure 3-5. TAS2564: dV/dt = 0.7 V/ns

For example, if we were to use a total capacitance of 250 pF on the 2V/ns output of TAS2770 we could expect to see a peak current into the capacitor of about 0.5 A.

If not selected carefully, a capacitor directly on the output will cause peak currents that exceed the over current protection of the amplifier. The maximum capacitor value will be directly related to the maximum of the current spike observed during the rise and fall of the output switching. This must always be selected to keep below the over current threshold of the amplifier. It is never recommended to design a capacitor only filter. If one is used, the maximum theoretical value should always be avoided. Process variations in ceramic capacitors are typically in the range of 10-20%. Designing near the maximum will typically result in a production unit that enters over current protection when driving power at levels within the typical maximum output power range. This practice also results with the greatest efficiency losses in the filter. After considering both of these concerns, it is always recommended to start the filter design with an inductiver or ferrite element first, and then add a capacitor as needed.

For best sound quality and power efficiency it is recommended to use the smallest capacitors required to pass emissions standards. With best practice layout guidelines and proper decoupling design, the capacitors on the output filter can often be kept quite small. For best results, use a filter which includes an inductive element , such as a ferrite bead, in series with the output and before the capacitor. This will prevent the capacitor from being exposed to the high dV/dt of the output switching as well as add second order filtering to remove the high frequency content.

4 References

- Texas Instruments, *TAS2770 20-W Digital Input Mono Class-D Audio Amplifier with Speaker I/V Sense* Data Sheet
- Texas Instruments, *TAS2562 6.1-W Boosted Class-D Audio Amplifier with IV Sense* Data Sheet
- Texas Instruments, *TAS2563 6.1-W Boosted Class-D Audio Amplifier With Integrated DSP And IV Sense* Data Sheet
- Texas Instruments, *TAS2564 7-W Class-D Smart Amp With Integrated 13-V Class-H boost & I/V Sense for Speaker Protection* Data Sheet