Application Report
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Post Filter Feedback Class-D Amplifier Benefits and Design Considerations

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ABSTRACT

This document details post filter feedback (PFFB) technology from Texas Instruments. It will guide designers through the audio system benefits that can be realized by implementing this technology inclusive of performance and cost.

Contents

1 Introduction 2
2 Post Filter Feedback (PFFB) 2
3 Loop Stability With PFFB 3

List of Figures

1 Class-D Loop With PFFB 2
2 TAS2560 THD+N vs Frequency Comparison 3
3 Ferrite Bead Equivalent Model 3
4 Impedance Curve for MPZ1608S221A 3

List of Tables

1 Comparison of Inductive Filters 2
2 PFFB Sability Criteria for TAS25xx Series 4

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1 Introduction

A Class-D audio amplifier output is a switching output that has a carrier frequency along with the audio signal content. These switching frequencies can lead to system design challenges with EMI radiation due to long traces running to the speaker loads. In order to meet EMI radiation specs like FCC/CE, the Class-D amplifier outputs typically have EMI filters realized using LC filters at the output. The inductor in the filter can be implemented using a ferrite bead, which is more cost optimized than a regular inductor, but comes with its own non-linearities. Using cost-optimized ferrite beads can degrade the THD performance of the audio after the filter, affecting the audio performance of the end system. Such concerns often lead designers to go back to an inductor based filter or use a more expensive ferrite bead which does not degrade the THD performance but ultimately increases the cost of the end system. Another concern with using a filter at output of a Class-D amplifier is that it degrades the frequency response of the output depending upon the cut-off frequency selected for the filter. This also affects the audio performance across frequencies. Table 1 lists the cost of different inductors and ferrite beads. The PFFB configuration from Texas Instruments™ allows usage of low cost ferrite beads without the performance degradation associated with these components.

Table 1. Comparison of Inductive Filters(1)

Part Number	Type	9 k Unit Price	Performance
MAKK2016TR24M	Inductor	$0.071	High
NFZ2MSM181SN10L	Ferrite bead	$0.111	High
MPZ1608S221A	Ferrite bead	$0.018	Low

(1) Sourced from mouser.com.

2 Post Filter Feedback (PFFB)

TI's PFFB allows the user to add the ferrite bead inside the Class-D loop as shown in Figure 1. This change in loop configuration ensures that the errors added by ferrite beads are added inside the Class-D loop and will get corrected by the loop gain. This coupled with the high loop gain that comes with TI's fourth order Class-D amplifiers in devices such as TAS2560, TAS2557, and TAS2559 amplifiers ensures that THD degradation due to the ferrite bead addition are minimized. This allows designers to use cost optimized ferrite beads without worrying about the adverse effects of these beads on their system's audio performance. Also, since the loop is closed after the ferrite beads filters, there is no dip in the frequency response of the amplifier which results in giving the amplifier a flat amplitude response across the audio band of frequencies.

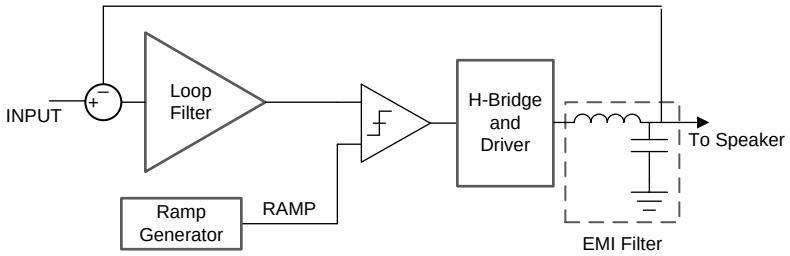

Figure 1. Class-D Loop With PFFB

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Figure 2 compares the THD+N vs Frequency for TAS2560 with MPZ1608S221A ferrite bead filter coupled with a 100-pF capacitor. As it is seen in Figure 2, the THD degrades significantly at higher frequencies when the ferrite bead is kept outside the Class-D loop like in traditional Class-D amplifiers. With TI's PFFB configuration, the performance degradation due to ferrite bead is greatly reduced.

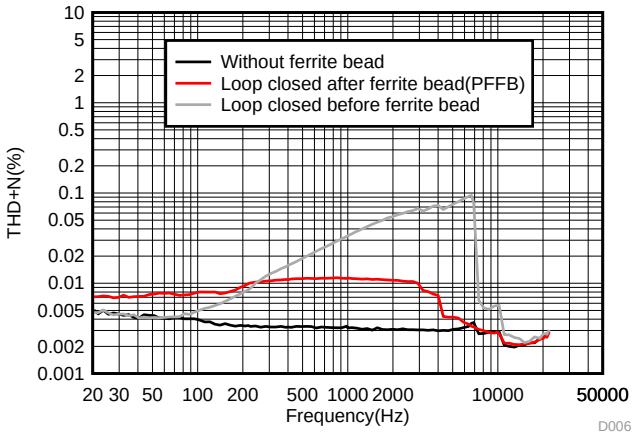

Figure 2. TAS2560 THD+N vs Frequency Comparison

3 Loop Stability With PFFB

Because the ferrite bead filter is now inside the Class-D loop, there are extra poles added in the system which adversely affect the stability of the loop. The designer must take into account extra guidelines in order to choose the correct configuration of the filter to ensure the Class-D loop is stable.

To find a stable configuration of the EMI filters, the equivalent model of the EMI filter needs to be drawn. The filter must be approximated into a second order filter as shown in Figure 3.

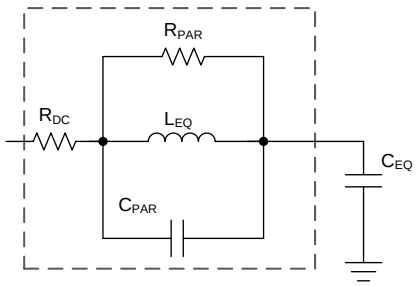

Figure 3. Ferrite Bead Equivalent Model

Ferrite beads impedance can be divided into three main regions (for example: inductive, resistive, and capacitive). These regions can be easily determined by looking at impedance plots of ferrite bead data sheet (shown in Figure 4), where Z is the impedance, X is the reactance, and R is the resistance of the bead.

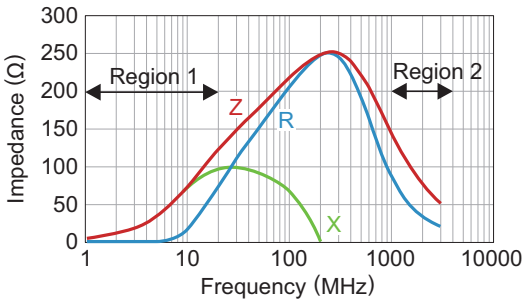

Figure 4. Impedance Curve for MPZ1608S221A

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For the region of the impedance plot where the bead appears mostly inductive (region 1 in Figure 4), the L_{EQ} can be calculated by using Equation 1. It is best to take the impedance value at least a decade away from the peak impedance value for accurate calculations. For example, impedance seen in Figure 4 at 10 MHz for the MPZ1608S221A is 70 Ω. L_{EQ} can be calculated as 1.11 µH.

$$L_{EQ} = \frac{X_L}{2 \times \pi \times f} \quad (1)$$

where

- X_L = impedance of the bead at frequency (f)

The C_{PAR} can be estimated in a method similar to L_{EQ}, by looking at region where the bead appears mostly capacitive (region 2 in Figure 4). The C_{PAR} can be estimated using Equation 2. It is best to take impedance value at least a decade away from the peak impedance value for accurate calculations. For most beads, the C_{PAR} is less than 5 pF and has no impact on the stability of the loop. User should do the calculations and ensure that this holds true for the bead selected for the use case. For example, impedance seen in Figure 4 at 1 GHz for MPZ1608S221A is 150 Ω. C_{PAR} can be calculated as 1 pF.

$$C_{PAR} = \frac{1}{2 \times \pi \times f \times X_C} \quad (2)$$

where

- X_C = impedance of the bead at frequency (f)

R_{PAR} can be approximated as the peak impedance of the bead. For ease of calculations, R_{DC} is approximated as zero here, and the entire peak impedance is estimated as R_{PAR}. In Figure 4, R_{PAR} can be calculated as 250 Ω.

The total output capacitance (C_{EQ}) should include the intentional capacitance added by the user for the filtering and the parasitic capacitors due to any other additional elements at output of the ferrite bead such as ESD diodes, board routings, and more.

Using the model of the filter, the filter cutoff frequency and the Q-factor can be calculated by using Equation 3 and Equation 4.

$$\omega_0 = \frac{1}{2\pi \times \sqrt{L_{EQ} \times C_{EQ}}} \quad (3)$$

$$Q = R_{PAR} \times \sqrt{\frac{C_{EQ}}{L_{EQ}}} \quad (4)$$

Table 2 summarizes the stability criteria for TI's PFFB, Class-D amplifiers. It is recommended that designers ensure the stability criteria for the selected filter satisfy the guidelines in Table 2 for proper functioning of the Class-D amplifier.

Table 2. PFFB Sability Criteria for TAS25xx Series

Part No.	Cutoff Frequency – ω_0	ω_0 / Q
TAS2560	> 10 MHz	> 2e6
TAS2557	> 10 MHz	> 2e6
TAS2559	> 10 MHz	> 2e6

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Date	Revision	Description
November 2017	*	Initial release.

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