

Line Driver Pop Noise Design Consideration on Subwoofer

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ABSTRACT

Pop and click, which can be observed through the portable speaker or headphone when you power on or off the power supply, is the name given to the popping noise. Pop and click, especially true for those destined for the SE input circuit, is a characteristic that makes a lot of impact in the world of audio amplifiers. This application report indicates the methods on how to eliminate the pop noise with minimal audio performance impact.

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1 Introduction

At the output stage of the class-D amplifier of power-on or power-off, the noise is generated by a voltage difference before it stays its steady state. Usually without proper circuit design or power sequence control, the system event related to the analog amplifier generates a click or a pop. For Class D amplifier of the audio portion, audible click sound, mainly depending on the both amplifier and the amplifier, is typically at PWM start and stop.

System design considers the pop sound at the system level at the beginning to avoid the pop noise. The power up and the power down is, in most occasions, the pop noise occurred. The power up and power down impacts the DC offset of amplifier input, which results in the voltage transient change. This short time voltage transient outputs and applies on the speaker to generate the undesired sound. If the audio input source change also has the possibility to get the voltage transient change, then the amplifier outputs the pop noise. For more details on how to define and measure the pop noise, see the [Click and Pop Measurement Technique](#).

Impedance mismatching on the input components will also dramatically impact the DC offset that mainly dominates the pop noise occasions on the system design.

Pop and click, which can be observed through the portable speaker or headphone when you power on or off the power supply, are the appellation given to the popping noise. Pop and click, especially true for those destined for the SE input circuit, is a characteristic that makes a lot of impact in the world of audio amplifiers. This application report indicates the methods on how to eliminate the pop noise with minimal audio low frequency attenuation impact on woofer application.

2 Smart TV Audio Systems Overview

Smart TV audio systems usually requires the entire audible range of frequencies, which is beyond the capability of any single mid-power (<30 Watt) speaker. The mid-power speaker operating frequency range is 100Hz to 18 kHz. Therefore, high-end TVs often combine several drivers to make more realistic sounds by designing line-out with an active external woofer with lower resonance frequency of 20Hz.

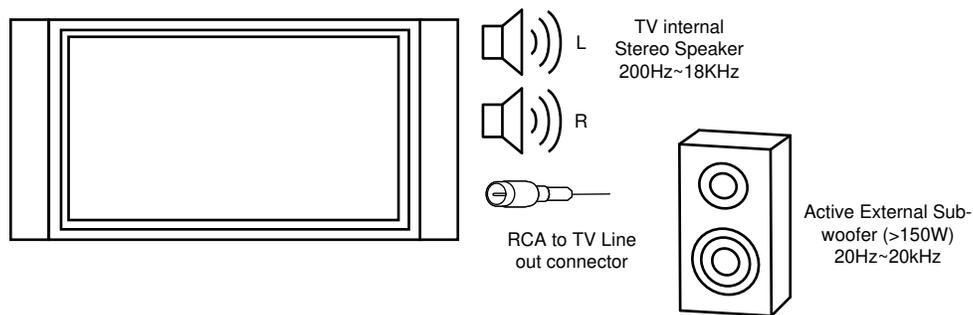


Figure 1. TV Sound Block Diagram for Smart TV Sound 2.1 CH Systems

3 TV 2.1CH Typical Application Design

TAS5760LD is very popular in the TV application, which integrates a stereo 20Watt class D amplifier with the line driver. Smart TV SOC can output inter-IC sound (I2S) and analog signals from the digital-to-analog converter (DAC) to the TAS5760LD class D amplifier that includes hardware and software inter-integrated circuit (I2C) control modes, integrated line driver, and a wide power supply operating range to enable use in a multitude of applications. Therefore, smart TV can adapt TAS5760LD to drive the twitter speaker and use the integrated line driver to drive external active woofer.

Typical circuit diagrams highlight the required external passive components and system level connections for proper operation. Figure 2 shows the stereo mixer circuit to mono line driver output. The design requirement is to make 20 to approximately 200Hz frequency response flat within $\pm 3\text{dB}$ range. The feedback network is around 1.5 V/V. In a general case, the line driver port output impedance is designed to 1 k Ω .

If the typical circuit follows the suggested power sequence as shown in Figure 3, there is no pop noise due to DirectPath architecture, which makes sure the output voltages are centered at zero volts with the capability to swing to the positive rail or negative rail.

In the TV system design, 3.3 V power of the line driver sometime tied to SOC's power supply. So, it is not able to do the power sequence control on line driver and SOC side. However, the SOC DAC output generated the larger transient while the SOC 3.3 V turned off, which resulted in the TAS5760LD line-in receive the unexpected transient.

The slightly voltage transient can be observed on the TAS5760 line out if TAS5760LD AVDD turns off and the design uses the line out to drive the external active woofer speaker. (>150Watt)

In the above design scenario, the output impedance design and the feedback network resistor design are critical factor here to minimize the voltage transient from SOC output. The design challenging is need to make sure the lower frequency 20 to approximately 200HZ within $\pm 3\text{dB}$ range during selecting the proper passive component values.

This application report, with TINA simulation and real PCB design cases, studies the relation between 1 k Ω and 270 Ω output impedance on pop noise improvement. Secondly, this application report discusses the approach by increasing the feedback network resistor values to improve the pop noise. The pop noise was improved by increasing the feedback network resistor 2 times value.

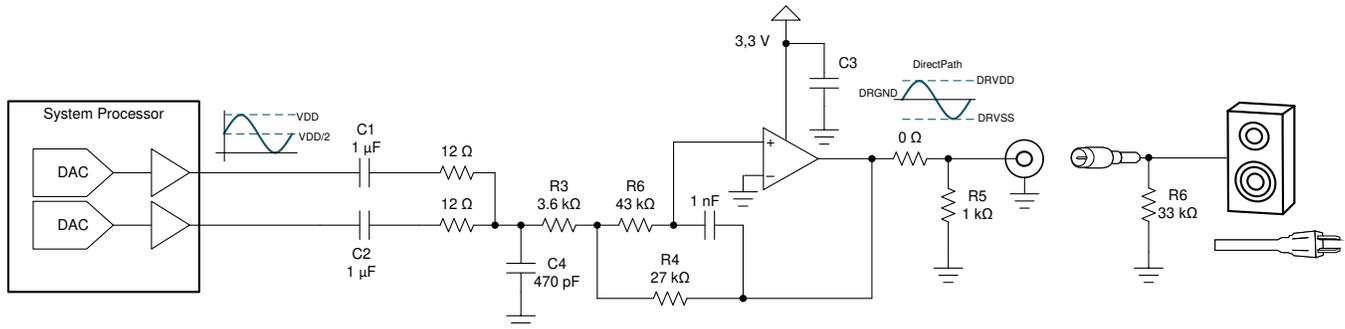


Figure 2. Subwoofer Line Driver Stereo to Mono Design

Resistor R5 and resistor R6 are parallel, their effective resistance R_{eff} can be determined from Equation 1. Here is the example for R_{lineout} 1 k Ω and R_{woofer} 33 k Ω case, the equivalent resistor is 1 k Ω .

$$R_{\text{eff}} = \frac{R_{\text{lineout}} \times R_{\text{woofer}}}{R_{\text{lineout}} + R_{\text{woofer}}} \approx 1 \text{ k}\Omega \quad (1)$$

Table 1. Design Parameters

Parameter	Example
Low Power Supply	3.3 V
High Power Supply	12 V
Host Processor	I2S and I2C
Output Filters	Inductor- Capacitor Low Pass Filter
Twitter Speakers	4 Ω or 8 Ω
External Active Woofer Speaker Input Impedance	33 k Ω
TAS5760LD Line Out	Mono
TV Output Impedance	1 k Ω
Line Out Driver Gain	1.5 V/V
Line Out Driver Frequency Response	20 to approximately 200Hz \pm 3dB

For the line driver power off, the SOC output usually has the DC level changed, which results in the voltage transient in the line driver input side. Before transient voltage happens, the line driver needs to maintain 3.3 V power supply and keep (DR_MUTE) as low level. This allows the TAS5760LD analog amp output impedance stay at 100 m Ω . The low impedance can effectively reduce the pop noise.

The power down sequence is discussed in [Section 3.1](#). The design needs to keep the line driver power at 3.3 V when turning down the SOC power 3.3 V.

3.1 Power Down Sequence

1. Mute TAS5760 HP.
2. Turn down SOC 3.3 V (output impedance keeps low. It can avoid pop).
3. Shutdown HP 3.3 V.

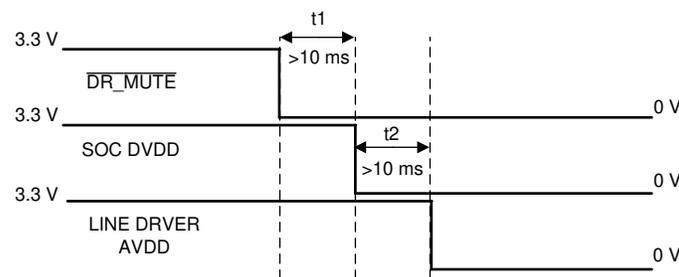

Figure 3. Line Driver Power Sequence

Figure 4 is frequency response TINA simulation of the typical line drive circuit (subwoofer stereo to mono line driver). The frequency response from 20Hz to approximately 200Hz is within ± 3 dB range.

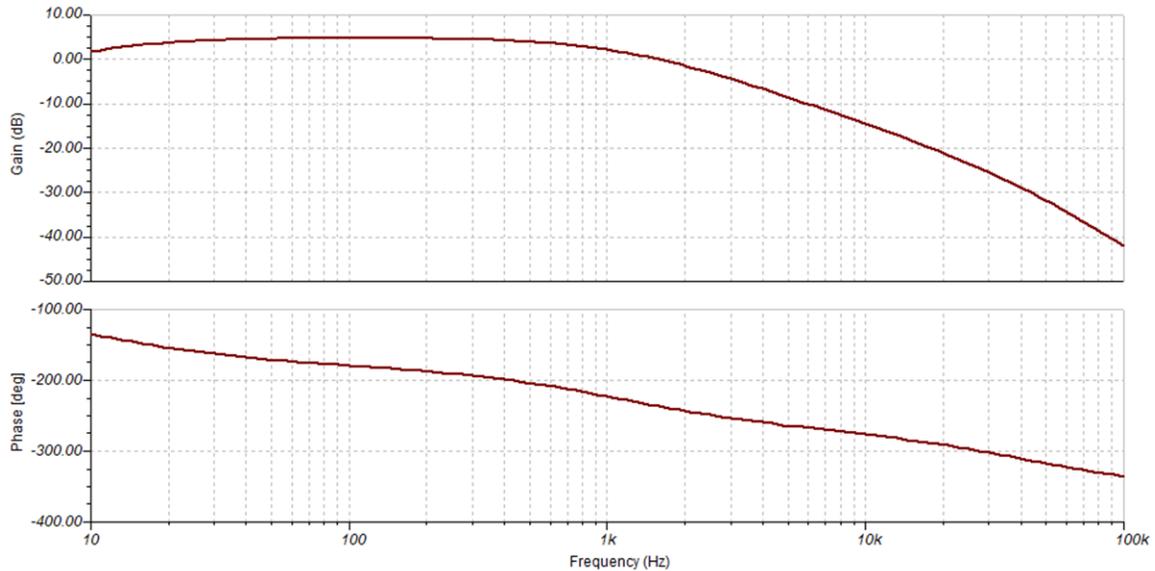


Figure 4. Frequency Response of Typical Subwoofer Line Driver Stereo to Mono Circuit

In Figure 5, the big DC level transient at the line driver input, but there is no transient voltage at line driver output. The reason is SOC 3.3 V power and line driver 3.3 V power are separated. The line driver 3.3 V power was not provided while there is big DC level transient from SOC's output. Figure 6 shows that the case SOC and line driver share the same 3.3 V power supply. The voltage drop in channel 1 due to 3.3 V power supply for SOC and line driver turns off at the same time. Channel 2's waveform shows the line driver of TAS5760LD output transient around -11mV. CH1 is input from SOC. R CH2 is line driver output. CH3 is (DR_MUTE) controlled waveform by SOC's GPIO. CH4 is 3.3V for line driver power.

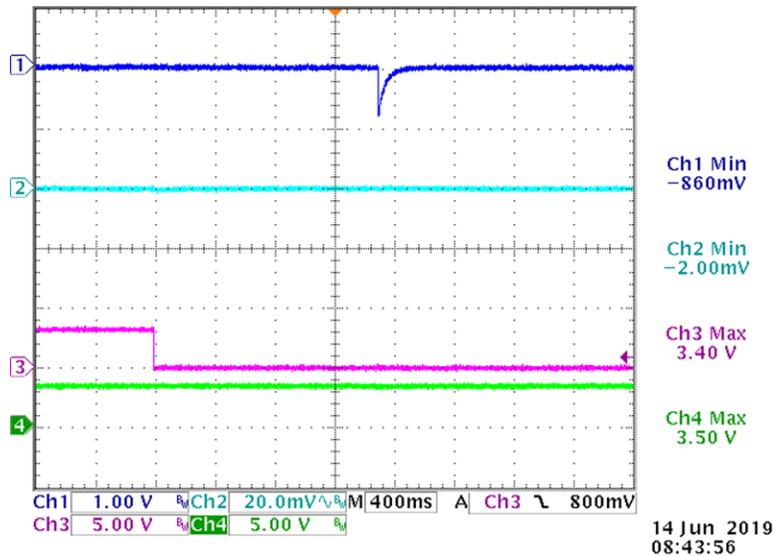


Figure 5. TAS5760LD Line Driver's Waveform With Proper Power Sequence

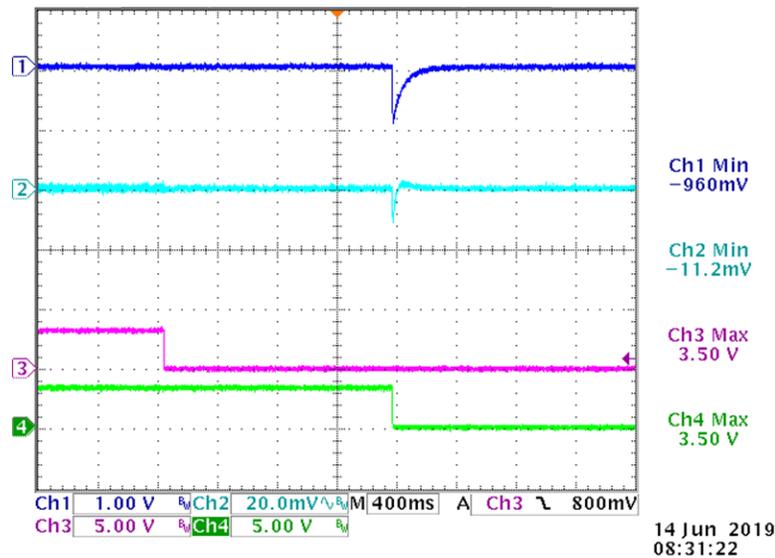


Figure 6. TAS5760LD Line Driver's Waveform With Improper Power Sequence

4 Approach on How to Minimize the Pop Noise

In this section, two design factors are discussed and simulated.

4.1 Terminations Resistor Design and Simulation

First, change the output impedance R5 from 1 kΩ to 270 Ω. The frequency response stays flat from 20Hz to 200Hz. This application report uses TINA to simulate the SOC bigger transient via step response method. VF1 is the Line driver output. Figure 9 shows the transient can be improved to around -6mV.

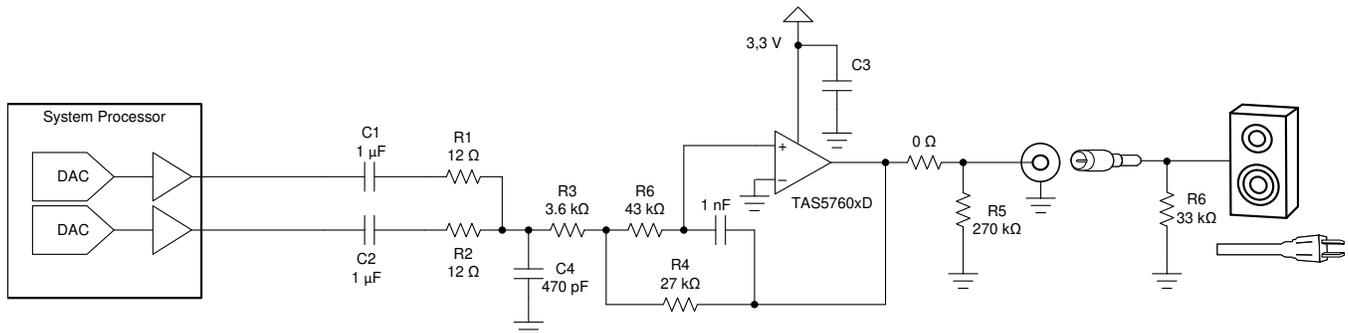


Figure 7. Subwoofer Line Driver Stereo to Mono Design With Output Impedance 270Ω Resistor

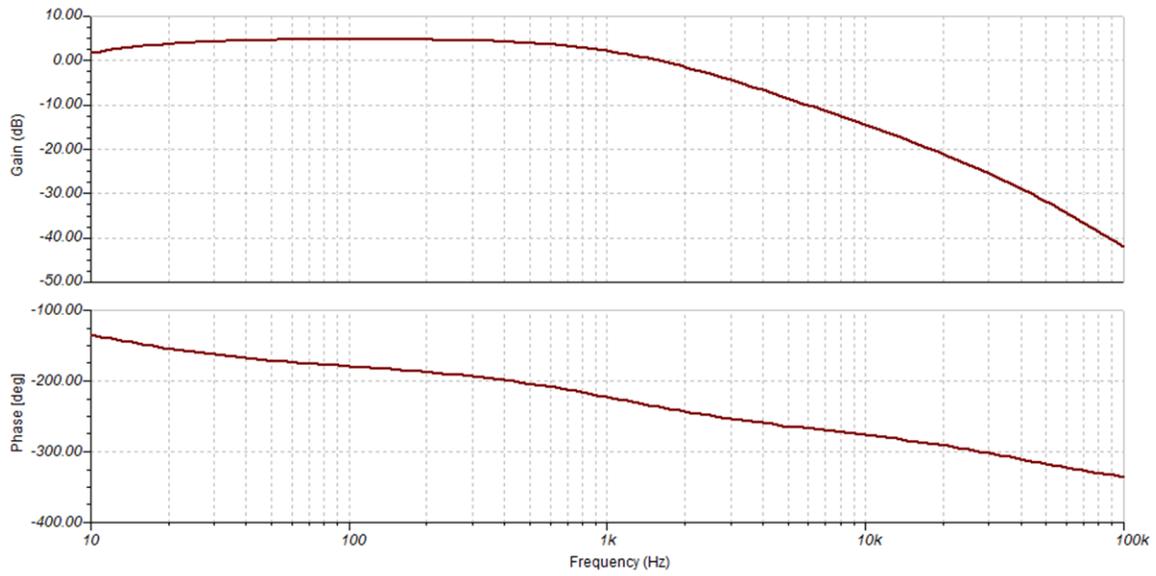


Figure 8. Frequency Response of Typical Subwoofer Line Driver Stereo to Mono Circuit

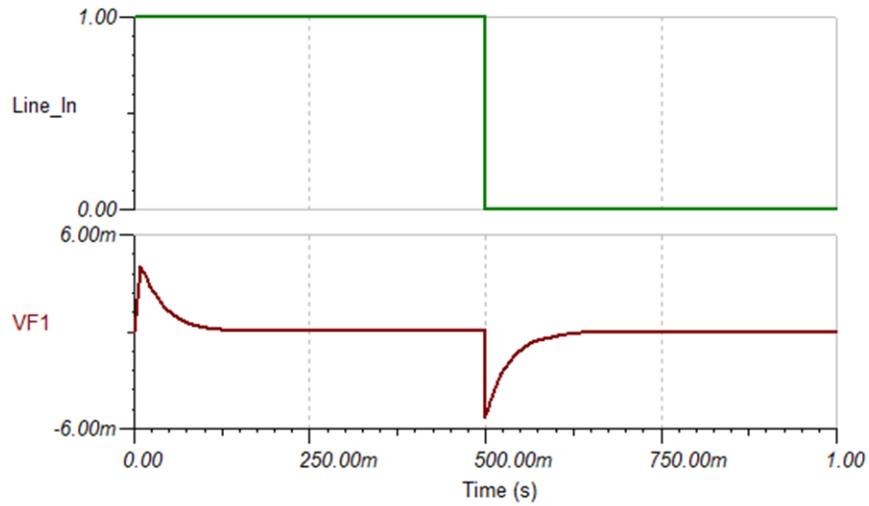


Figure 9. Step Response of Typical Subwoofer Line Driver Stereo to Mono Circuit

4.2 Feedback Resistor Network Design and Simulation

The design changes the feedback network resistor twice. The design feedback network resistors values are list in Table 2. From TINA's simulation, the frequency response of Figure 11 stays flat from 20Hz to 200Hz. Step response simulation of Figure 12 shows that the VF1 (the Line driver output) transient can be improved from -6 mV to -2.5 mV.

Table 2. Design Parameters on the Feedback Network Resistors

Parameter	Example
R1	24 kΩ
R2	24 kΩ
R3	7.5 kΩ
R4	56 kΩ
R5	270 Ω

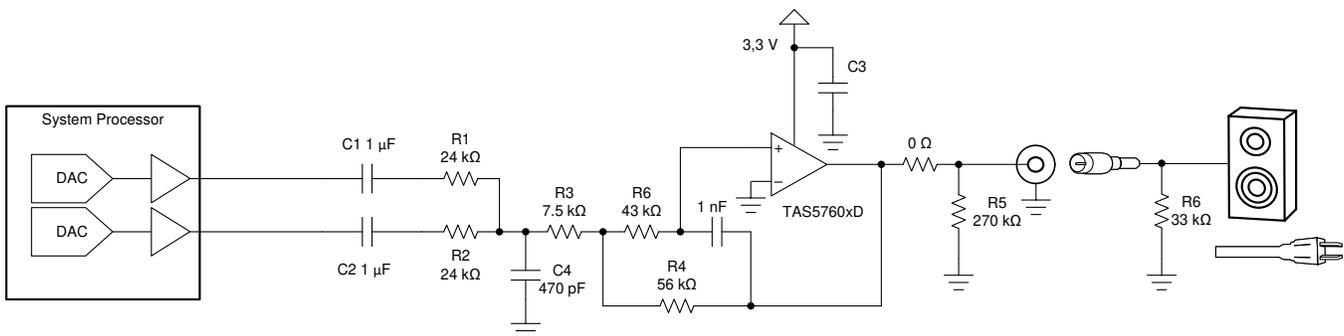


Figure 10. Subwoofer Line Driver Stereo to Mono Design With Output Impedance 270Ω Resistor and Twice Feedback Network Resistor

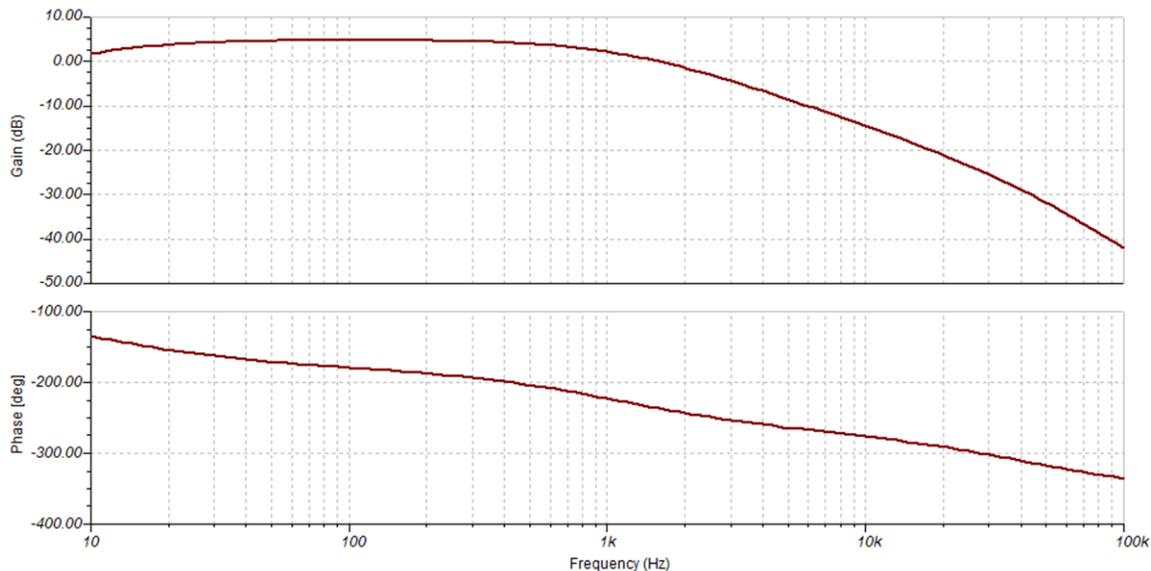


Figure 11. Frequency Response of Termination Resistor 270Ω. Increase the Feedback Resistor Values but Keep the Same Gain Level

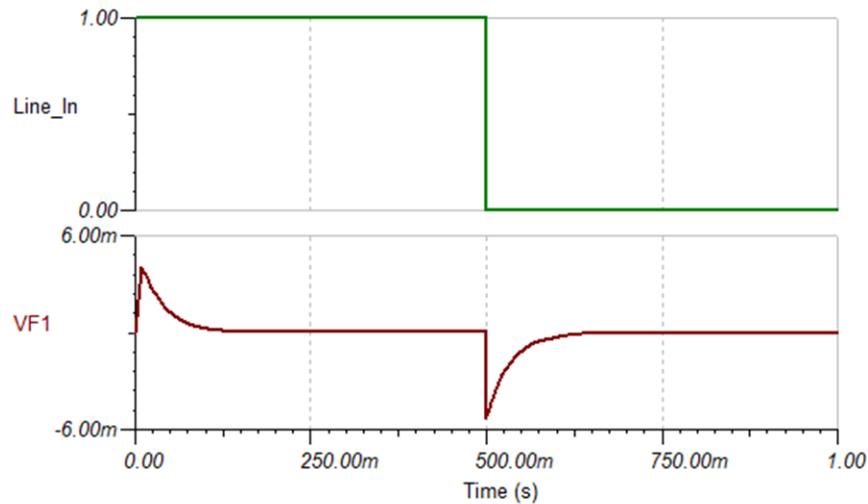


Figure 12. Step Responses With Termination Resistor 270 Ω. Increase the Feedback Resistor Values but Keep the Same Gain Level

Replacing the 0 Ω resistor with the 47 nF high-pass capacitor can improve the transient from -6 mV to -1.6 mV. However, adding a high-pass capacitor also dramatically sacrifices the low-frequency response 20Hz to 200Hz. Therefore, using the high-pass capacitor at the line driver output is not suitable for the subwoofer line driver application

5 Results on the Practical Application

If the TAS5760 line driver shares the same 3.3 V with SOC, then the circuit designer can considerably reduce the output termination resistor and increase the feedback resistor values.

5.1 Terminations Resistor Design With Practical Application Waveform

On a real application, the output transient is improved from -11 mV to -2 mV as shown in [Figure 13](#) by decreasing termination resistor from 1 kΩ to 270 Ω resistor.

Pros: Termination resistor decrease the output transient obviously.

Cons: The current is higher if using smaller termination resistor. From [Equation 2](#), the power consumption increases 3.7 times if using 270 Ω resistor.

$$\text{Power} = \frac{V^2}{R} \tag{2}$$

$$\text{Increasing Power} = \frac{P_2}{P_1} = \frac{1 \text{ k}}{270} = 3.7 \text{ times} \tag{3}$$

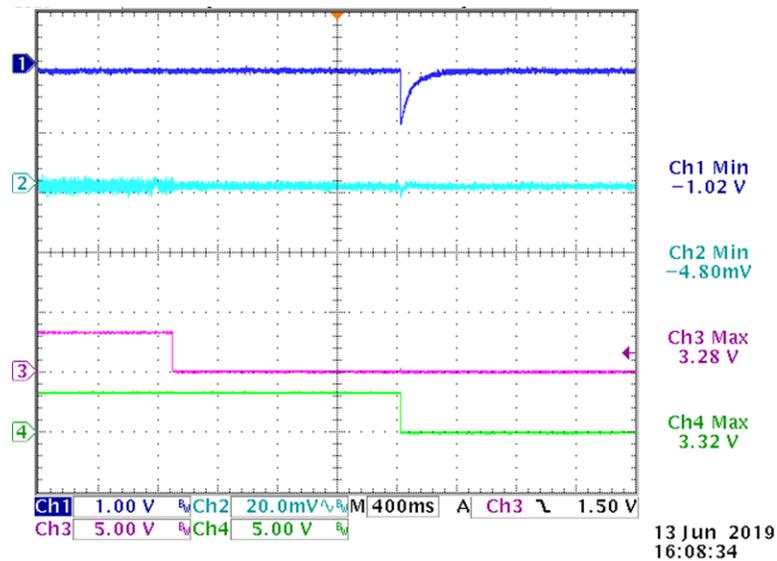


Figure 13. TAS5760LD Line Driver's Waveform With 270 Ω Termination Resistor

CH1 is input from SOC. CH2 is line driver output. CH3 is (DR_MUTE) controlled waveform by SOC's GPIO. CH4 is 3.3V for line driver power. The output transient is improved from -11mV.

5.2 Feedback Resistor Network Design With Practical Application Waveform

The circuit further increases the feedback gain resistor network value 2 times as shown in Table 2. The output transient is implicit due to the level is almost as same as the background noise.

Cons:

$$V_n = [4KTRB(\text{Hz})]^{1/2} \quad (4)$$

where, $K = 1.38 \times 10^{-23}$ J/K is Boltzmann's constant, T is the absolute temperature (K), and $B(\text{Hz})$ is the bandwidth of the system.

$$\text{Increasing Thermal Noise} = \frac{V_{n2}}{V_{n1}} = \left(\frac{R_2}{R_1} \right)^{0.5} = (2)^{0.5} = 1.414 \text{ times} \quad (5)$$

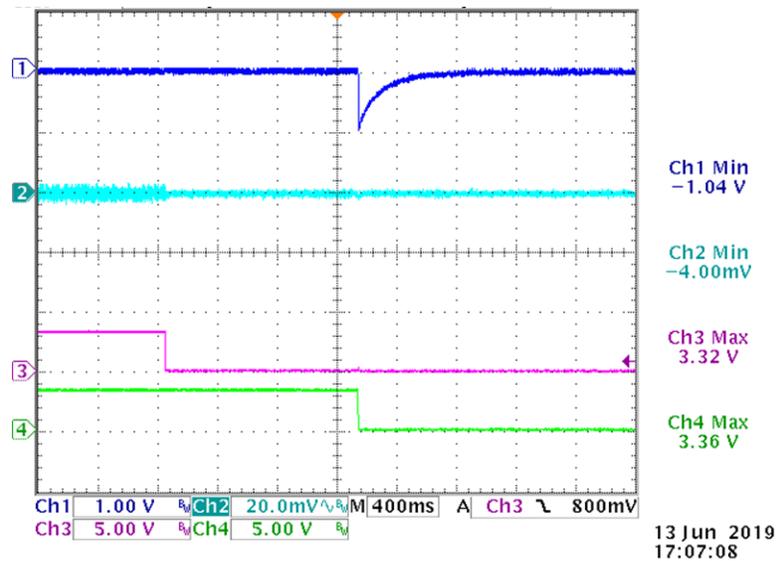


Figure 14. Increasing Line Driver Feedback Resistor Network's Waveform With 270Ω Termination Resistor

CH1 is input from SOC. CH2 is line driver output. CH3 is (DR_MUTE) controlled waveform by SOC's GPIO. CH4 is 3.3V for line driver power.

5.3 Conventional Solution With External BJT Switch

If the design still cannot resolve the pop noise, the conventional solution is that the SOC uses general-purpose input/output (GPIO) to control the external BJT. Figure 15 shows the implementation on how to use BJT at the output stage.

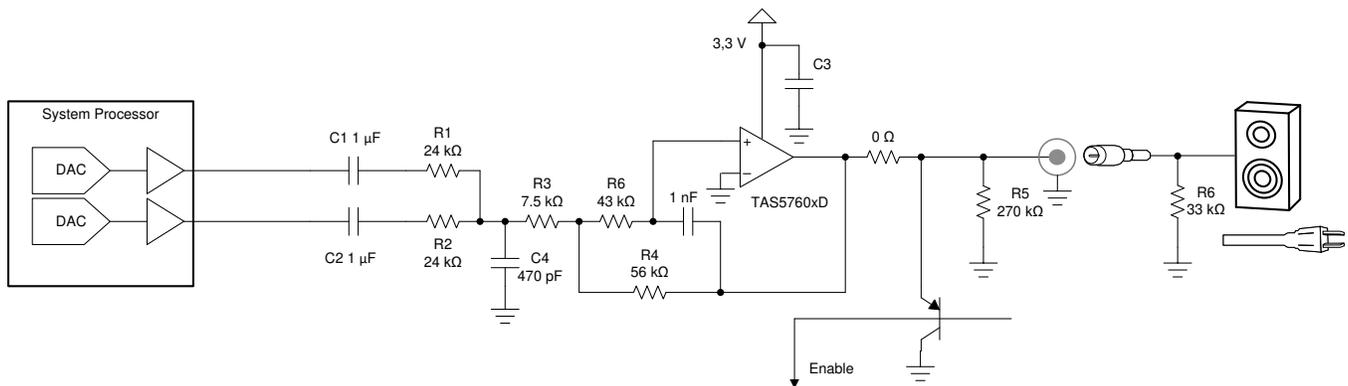


Figure 15. System Processor Control External BJT Before System Turns Off

5.4 Cap Selections

The capacitor selection in the analog amplifier is also important to the pop noise. Usually, the capacitors should have a tolerance of $\pm 10\%$ or better because the capacitor mismatch causes an impedance mismatch at the corner frequency and below if the corner frequency is within the audio band. For a flat low-frequency response, use large input coupling capacitors (1 μF).

Increasing the input capacitor may slightly improve pop performance as well. Increasing the input capacitor from 1 μF to 2.2 μF will slow the turn-on time of the amplifier, which may make any pop noise less noticeable.

Adding the capacitor before the input capacitor to ground, the short time voltage transient will go through the capacitor to the ground loop. However, the capacitor value is important for the high frequency performance. If the value is too larger, it will shrink the higher frequency response performance.

High-K capacitors, like Y5V and Z5U, that have large temperature coefficients typically also have wide tolerances, so the frequency response variability is large. These capacitors can cause large variations in audio performance. X5R/X7R material capacitor is more suitable for the input capacitor options.

6 Summary

The application report discusses the low-frequency line driver design to prevent pop noise. If the audio system has the pop noise, it usually takes time to find out the root cause. The methods for the pop noise solving, depending on the woofer application desired, are addressed in the application report by either decreasing the termination resistor or increasing the feedback network resistor from simulation to real PCB board's waveform. However, if you able to separate the power from SOC, using correct power sequence can effectively prevent the pop noise and keep the lower frequency ($>20\text{Hz}$) response flat.

7 References

- Texas Instruments: [TPA2011D1 3.2-W Mono Filter-Free Class-D Audio Power Amplifier With Auto-Recovering Short-Circuit Protection Data Sheet](#)
- Texas Instruments: [TPA3110D2 15-W Filter-Free Stereo Class-D Audio Power Amplifier With Speakerguard™ Data Sheet](#)
- Texas Instruments: [TAS5760MD General-Purpose I2S Input Class-D Amplifier With DirectPath™ Headphone and Line Driver Data Sheet](#)
- Texas Instruments: [DirectPath™, 3-VRMS Line Driver With Adjustable Gain Data Sheet](#)
- Texas Instruments: [Click and Pop Measurement Technique](#)
- [Development of woofer microspeakers used cellular phones](#)

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