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Class D Amplifiers of LC823450 Series for Audio Applications

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APPLICATION NOTE

Introduction

This application note describes Class D Amplifiers (called D−AMP hereafter) guideline to enable customers to control D−AMP correctly in their application.

Intended audience is customers who are building audio application using LC823450 Series (called LC823450 hereafter).

Background

D−AMP Structure

LC823450 has two D−AMP for L channel and R channel internally. D−AMP is composed of DAC and AMP. DAC is mainly composed of Interpolator, Delta-Sigma Modulator and PWM Generator as shown in Figure 1.

Regarding the DAC part, Interpolator is a 8times interpolator which converts sampling frequency (Fs) up to 8 Fs by digital filter. Delta-Sigma Modulator at first converts input data up to 3times oversampling by sample & hold logic, and it does delta-sigma modulation. Delta-Sigma Modulator also has 9 levels or 17 levels for quantization, and it is processed with timing based on 24 Fs. PWM Generator generates a PWM signal with 1 bit width based on Delta-Sigma Modulator output and its period is 1/24 Fs.

The AMP part is a dedicated I/O buffer for D−AMP and it has an impedance control function to be used while it is turning on or off.

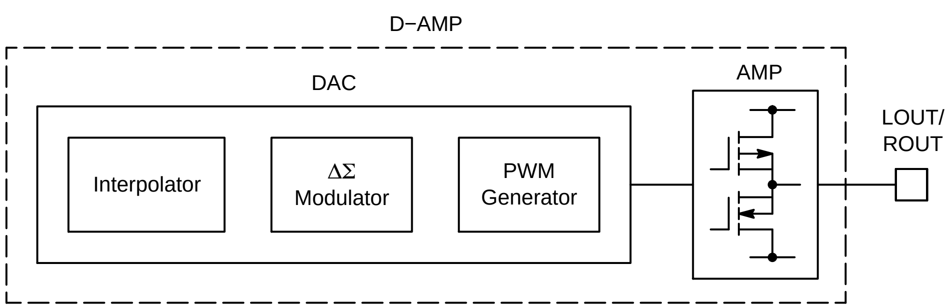

Figure 1. D−AMP Block Diagram

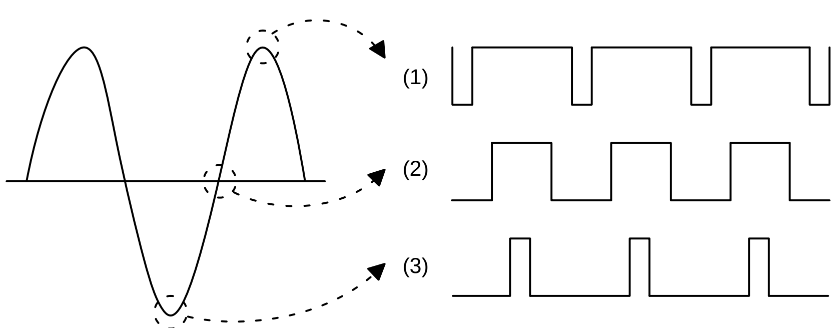

Figure 2. PWM Generation

Figure 2 shows characteristic of the PWM signal. DAC works to generate the PWM signal showing that high level code like the top part of the sine wave is converted so that high level of the PWM continues for long time such as (1), middle level code like the middle part of the sine wave is converted so that the duty of the PWM is around 50:50 such as (2) and low level code like the low part of the sine wave is converted so that low level of the PWM continues for long time such as (3). Delta-Sigma Modulator causes this modulation.

D−AMP Guideline

Need of LCR Filter

A PWM signal generated from each LOUT/ROUT terminal needs to be passed through an external LCR filter. If the LCR filter is not connected to LOUT/ROUT externally, the speaker connected directly to LOUT/ROUT terminal will be damaged strongly or may be broken because the PWM signal has strong power spectrum at around 24 Fs (1.0584 MHz if Fs is 44.1 kHz) and its overtone especially. Therefore, the LCR filter has to be connected to LOUT/ROUT directly and externally to cut off the frequency over the audible range.

Structure of LCR Filter

Figure 3 shows a LCR filter in case of Single-End form. Single-End form is a general form and it needs a 220 μF coupling capacitor to each channel. It is suitable for stereo sound, or monaural sound using only L channel.

Figure 4 shows a LCR filter in case of BTL form. BTL form generates an audio signal at one channel and the inverse of the audio signal at the other channel. Therefore, voltage amplitude at headphone for BTL form will be twice as high as Single-End form. Then, it doesn't need any coupling capacitor, but it is suitable for only monaural sound.

LCR filter composed of resistor R_D, inductor L and capacitor C is connected to each LOUT/ROUT terminal directly in Figure 3 or 4. After this filter, PWM signal will be an analog audio signal.

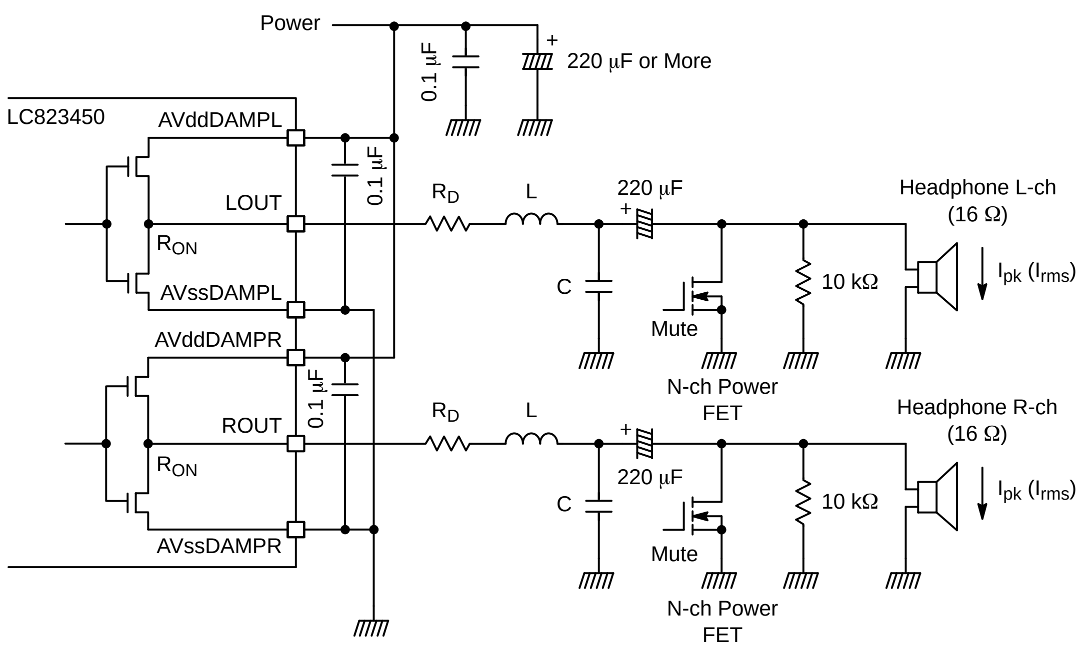

Figure 3. Single-End Form

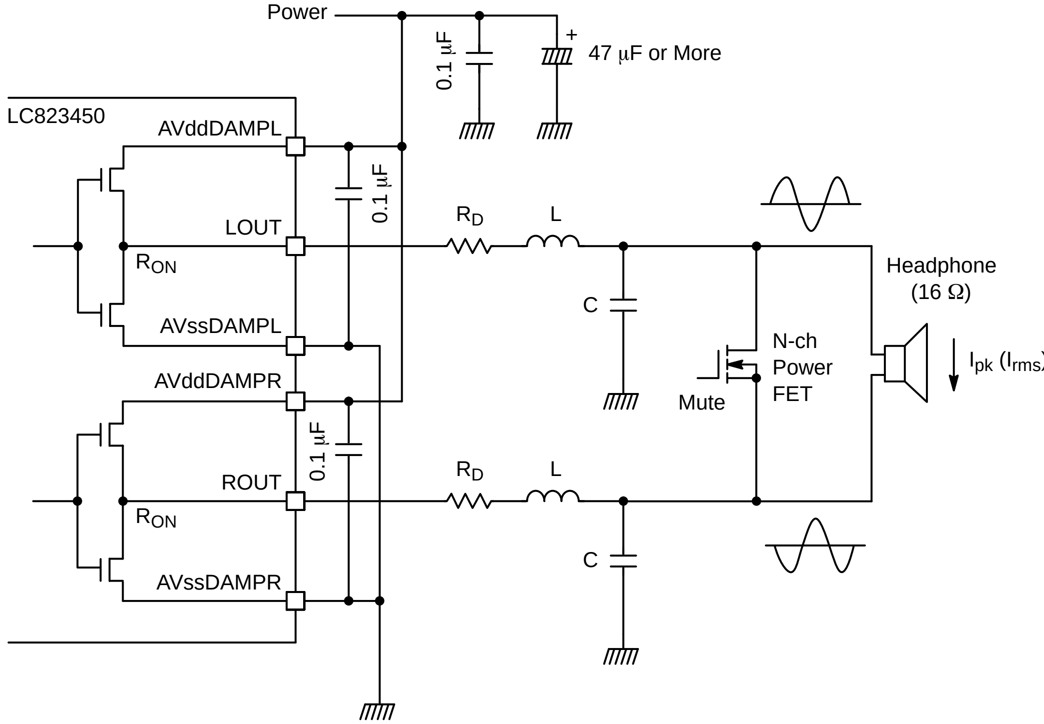

Figure 4. BTL Form

Table 1 shows an example of LCR filter parameter for Single-End form and BTL form. Regarding R_D resistor, if its value is large, it will reduce output gain of D−AMP, but it can reduce Q factor of LCR filter. The filter of Type A in Table 1 can select 0 Ω R_D resistor. In this case, the filter will hardly reduce output gain in the audible range, but 220 μH inductor will be large size physically. The filter of Type B in Table 1 can use 47 μH inductor which is smaller size physically, but it can't select 0 Ω R_D resistor because Q factor of the LCR filter in this case is too high, so several Ω R_D resistor needs to be used in the filter of Type B to reduce the Q factor. The filter of Type B will be suitable for small size inductor system.

Then, R_D resistor value needs to be chosen to fit the actual system, and it needs to be determined considering parasitic resistance of L. This table is an example and a guideline, and you may adjust the parameters of LCR filter according to the actual system. In addition, LC823450XGEVK which is an evaluation board made by ON Semiconductor uses an LCR filter parameter which is 47 μH inductor L, 1 μF capacitor C and 4.7 Ω resistor R_D because inductor L has around 2 Ω parasitic resistance.

Table 1. EXAMPLE OF LCR FILTER PARAMETERS

LCR Filter	L	C	R_D*
Type A	220 μH	0.22 μH	0−10 Ω
Type B	47 μH	1 μH	5−10 Ω

*R_D doesn't include parasitic resistance of L.

Reduction of Pumping Phenomenon

Pumping phenomenon shows that power supply voltage supplied for the power supply terminals of D−AMP rises up only a little when the audio signal at the headphone swings to negative voltage. It happens especially in case of Single-End form.

As shown in Figure 5, when the headphone swings to negative voltage, LOUT/ROUT terminal generates a signal showing high level period (t_1) is shorter than low level period (t_2). In this case, P-ch Tr of D−AMP is switched on for the period of t1 to generate high level output, and the negative current (I_L) of the inductor flows into the LOUT/ROUT terminal due to a self-induction action of the inductor and then it will flow into the regulator (I_a) through the P-ch Tr of D−AMP. If the regulator doesn't have ability to sink current, the output voltage (V_a) of the regulator will rise up according to sound loudness of the headphone. Then, pumping phenomenon is easy to happen at very low frequency sound like several ten Hz in the audible range because of negative swing for long time. In addition, shakes of the power supply voltage by pumping phenomenon will cause distortion of the audio signal on audio characteristics.

Therefore, the capacitor C_D for power supply is important, 220 μF or more capacitor C_D needs to be set to D−AMP power supply terminals in case of Single-End form to reduce fluctuation of power supply voltage by pumping phenomenon.

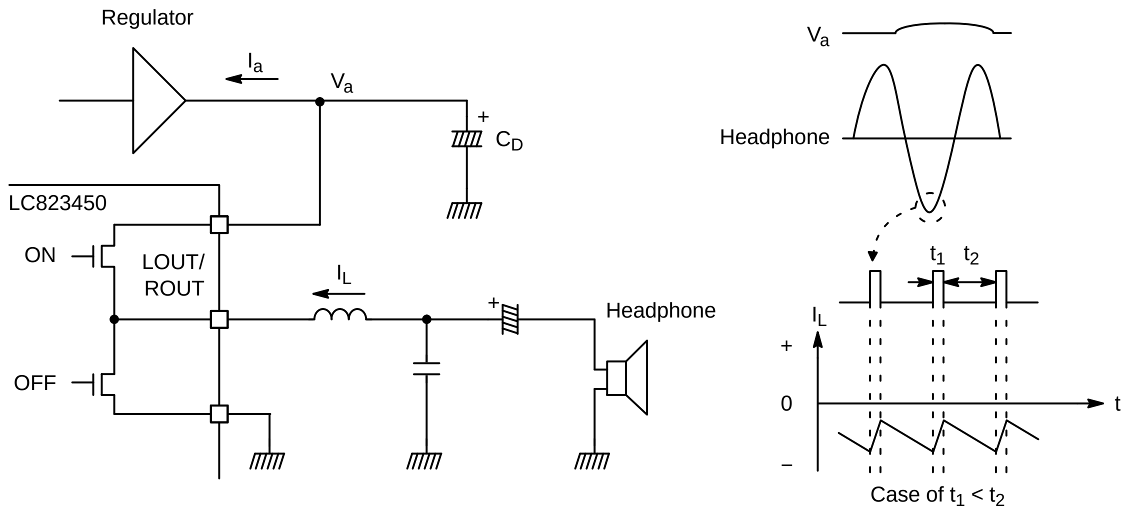

Figure 5. Pumping Phenomenon

On the other hand, in case of BTL, there is always a output path of the current (I_a). The current (I_a) which is flowed into the regulator through the p-ch Tr of one channel of D−AMP flows out to the p-ch Tr of the other channel of D−AMP because two audio signals of each channel have an inverse relation each other, so you can use smaller value of the capacitor Cd than Single-End form. For example, the capacitor Cd of 47 μF or more is suitable for BTL form.

Reduction of Pop Noise

The AMP part of D−AMP has an impedance control function as shown in Figure 6. This function is controlled so that the impedance of D−AMP buffer can be decreased from OFF(Hi-z) state (0x00000) to ON state (0x3FF00) when D−AMP turns on and can be increased from ON state (0x3FF00) to OFF(Hi-z) state (0x00000) when it turns off. Then, the normal operation works in ON state (0x3FF00).

This function is available to reduce pop noise that pop sound happens at mute state when D−AMP turns on or off.

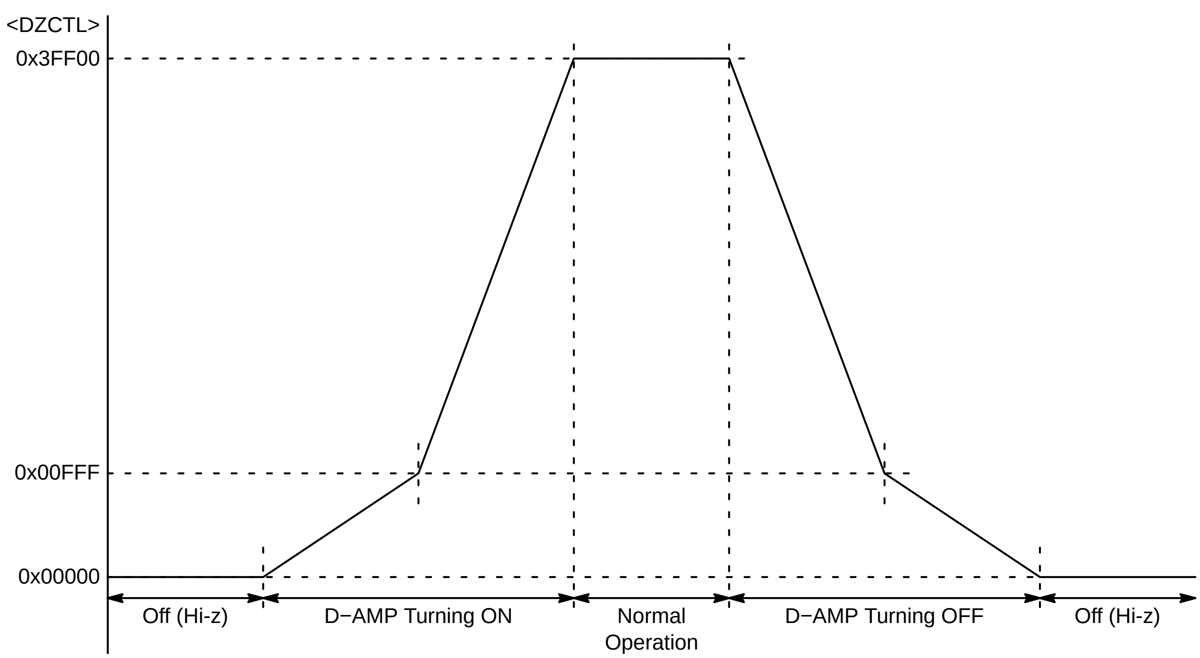

Figure 6. Hi-z Control by Impedance Control Function

Figure 7 shows simple mechanism of pop noise reduction for Single-End form. In this example, a PWM signal with duty 50:50 as a mute signal is input to D−AMP Buffer and output to LOUT/ROUT terminal (a), the voltage level after LC filter will go to 1/2 V_{DD} at steady state (b) and the voltage level of headphone will go to the ground level at steady state (c).

Case 1 is a case that D−AMP Buffer has no impedance control function, when D−AMP turns on, the PWM signal will soon be output to LOUT/ROUT terminal (a). Then, the voltage level at (b) will rise up to 1/2 V_{DD} according to the time constant of L and C, and the voltage level at (c) will go to the ground level according to the time constant of Cp and headphone resistance after it rises up to ΔV1. ΔV1 will be higher because the voltage level at (b) soon go to 1/2 V_{DD}.

Case 2 is a case that D−AMP Buffer has the impedance control function, when D−AMP turns on, the PWM signal will slowly be generated decreasing the impedance of D−AMP Buffer according to Figure 7 (a). Then, the voltage level at (b) will also slowly rise up to 1/2 V_{DD}, and the voltage level at (c) will also slowly rise up to ΔV2 and go to the ground level. ΔV2 will be lower because the voltage level at (b) very slowly go to 1/2 V_{DD}.

The voltage level at (c) is headphone voltage to the ground and it causes sounds, so ΔV1 in Case 1 and ΔV2 in Case 2 cause pop noise at mute state. However, ΔV2 is very lower than ΔV1 because D−AMP Buffer has the impedance control function, so the function can reduce pop noise.

By the way, in case of BTL form, the difference of both the voltage level at (b) of LOUT and one of ROUT directly means the voltage between both terminals of headphone and it causes sounds and it will become pop noise at mute state.

As a cause of the difference of them, D−AMP Buffer has variation of the impedance between LOUT and ROUT, and the parts composed of LCR filter also have variation of the value. These will cause pop noise because how to rise up of the voltage level at (b) is not perfectly the same between LOUT side and ROUT side.

If D−AMP Buffer has the impedance control function, the voltage level at (b) will rise up very slowly and then the voltage difference will also be smaller. Therefore, the impedance control function can reduce pop noise.

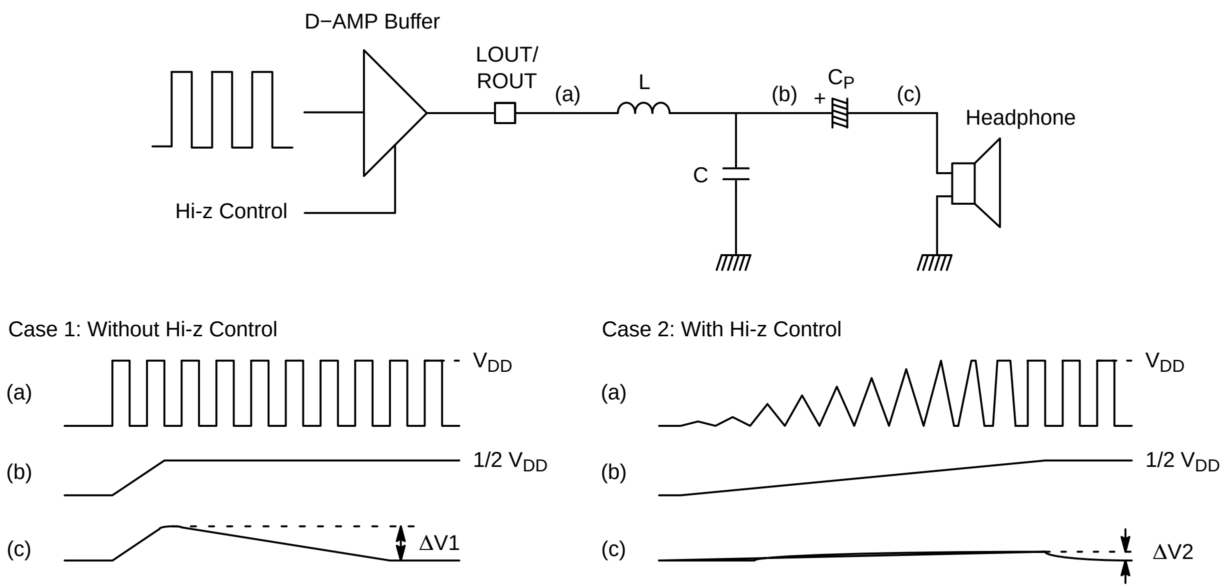

Figure 7. Pop Noise Reduction for Single-End Form

In addition, you can add a FET as shown in Figure 3 and Figure 4 to reduce pop noise further. The gate of the FET should be controlled by a GPIO of LC823450 passing through a low pass filter composed of resistor R and capacitor C.

Calculation of Electric Power Supplied to Headphone

Figure 8 shows simple calculation of electric power supplied to headphone at 0 dB full scale. It is estimated simply under the condition below.

- Resistance of inductor and capacitor can be ignored.
- Maximum voltage amplitude of PWM is 90% to D−AMP power supply.

For example, if D−AMP power supply V_{DD} is 1.2 V, D−AMP Tr ON resistance R_{ON} is 2 Ω, R_D resistor is 0 Ω and headphone resistance R_L is 16 Ω in Figure 8, electric power supplied to headphone at 0 dB full scale: P_{rms} is 7.2 mW in Single-End form and 23.3 mW in BTL form. Then, in this case, efficiency of power conversion: H is 88.89% in Single-End form and 80.0% in BTL form.

<Single-End Form>

$$I_{pk} = \frac{V_{DD}}{2} \cdot \frac{0.9}{R_{ON} + R_D + R_L}$$

$$I_{rms} = \frac{I_{pk}}{\sqrt{2}}$$

$$P_{rms} = I_{rms}^2 \cdot R_L$$

$$H = \frac{R_L}{R_{ON} + R_D + R_L}$$

<BTL Form>

$$I_{pk} = \frac{V_{DD} \cdot 0.9}{2 \cdot (R_{ON} + R_D) + R_L}$$

$$I_{rms} = \frac{I_{pk}}{\sqrt{2}}$$

$$P_{rms} = I_{rms}^2 \cdot R_L$$

$$H = \frac{R_L}{2 \cdot (R_{ON} + R_D) + R_L}$$

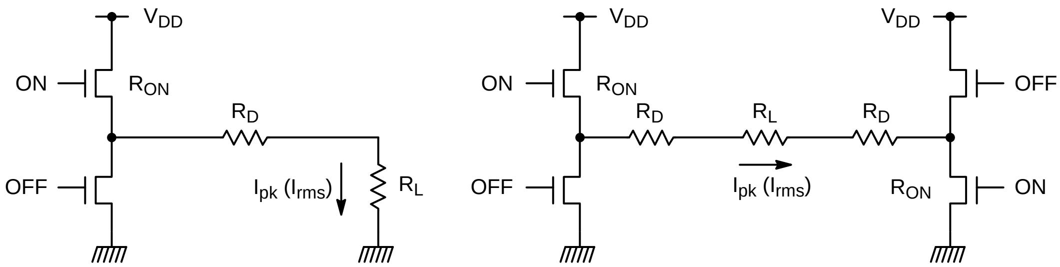

Figure 8. Model for Power Supplied to Headphone

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