Application Report
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DAC Post-Filter Design Based on DRV6xx Family

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ABSTRACT

This application report describes DAC post-filter design based on the Texas Instruments DirectPath™ line driver products. Theories, detailed design steps, and application circuits are discussed for Blu-ray™ DVD players, as an example. These theories, detail design steps, and application circuits are applicable to any other applications with the use of DACs.

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1 Introduction

The DRV6xx family of devices is 2-to-3 Vrms, pop-free, stereo line drivers, which are designed to allow simplified system architecture and reduce total component count and cost. Designed using the Texas Instruments patented DirectPath™ technology, the device integrates a charge pump to generate a negative supply rail that provides a clean, pop-free, ground-biased output capable of driving up to 2 Vrms with only a single 3.3-V supply voltage.

The DRV6xx family has built-in shutdown control (Enable pin) for pop-free, on/off control. Some family members such as the DRV603 have an external undervoltage protection (UVP) pin that can be used to detect system power loss and mute the outputs automatically. This function can fully eliminate pop noise generated by a prestage circuit (such as a DAC) during power loss.

DirectPath is a trademark of Texas Instruments.
Blu-ray is a trademark of Blu-ray Disc Association.

These advantages make the DRV6xx family excellent choices for digital-to-analog converter (DAC), 2-Vrms-output, post-filter applications, especially in television, set top box, and Blu-ray DVD audio line-out applications. This application report describes a step-by-step guide for DAC post-filter design based on the DRV6xx family.

2 DAC Post-Filter Design Principles

2.1 Butterworth Filter Basics

The Butterworth filter architecture provides maximum pass-band flatness and is often used as a post-filter for DAC outputs, providing flat gain in the 20-Hz to 20-kHz audio frequency range. A second-order filter also helps suppress out-of-band noise with an attenuation of 40 dB/decade.

The general transfer function of second-order, low-pass filter is:

$$H(f) = \frac{H_0}{1 + a_1 \frac{f}{f_c} \times j + b_1 (\frac{f}{f_c} \times j)^2} \tag{1}$$

The quality factor Q of the low-pass filter (Equation 1) is defined as:

$$Q = \frac{\sqrt{b_1}}{a_1} \tag{2}$$

For a Butterworth filter, the filter coefficients are as shown in Table 1.

Table 1. Coefficients for Butterworth Filter

Butterworth Second-Order, Low-Pass Filter Coefficients			
Parameter	**a1**	**b1**	**Q**
Value	1.414	1	0.707

2.2 Butterworth Filter Design Based on MFB

A Butterworth low-pass filter can be created by a multiple feedback (MFB) topology circuit with appropriate parameters; a single-ended input MFB circuit is shown in Figure 1:

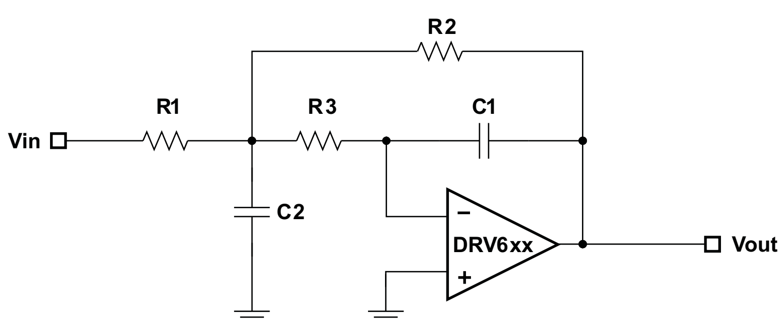


Figure 1. Single-Ended Input MFB Topology

The transfer function of the circuit in Figure 1 is:

$$H(f) = \frac{-\frac{R_2}{R_1}}{1 + 2\pi f_c C_1 \left(R_2 + R_3 + \frac{R_2 R_3}{R_1}\right) \frac{f}{f_c} \times j + (2\pi f_c)^2 C_1 C_2 R_2 R_3 \left(\frac{f}{f_c} \times j\right)^2} \tag{3}$$

Coefficient comparison with Equation 1 obtains the following relations:

$$H_0 = -\frac{R_2}{R_1}$$
$$a_1 = 2\pi f_c C_1\left(R_2 + R_3 + \frac{R_2R_3}{R_1}\right) = 1.414$$
$$b_1 = (2\pi f_c)^2 C_1C_2R_2R_3 = 1$$

(4)

Given C1, C2, and H0, and solving for the resistors R1, R2, and R3:

$$R_2 = \frac{a_1C_2 \pm \sqrt{a_1^2C_2^2 - 4b_1C_1C_2(1-H_0)}}{4\pi f_c C_1C_2}$$
$$= \frac{1.414 \times C_2 \pm \sqrt{(1.414 \times C_2)^2 - 4 \times C_1C_2(1-H_0)}}{4\pi f_c C_1C_2}$$
$$R_3 = \frac{b_1}{4\pi^2 f_c^2 C_1C_2R_2} = \frac{1}{4\pi^2 f_c^2 C_1C_2R_2}$$
$$R_1 = -\frac{R_2}{H_0}$$

(5)

In order to obtain real values for R2, C2 one must satisfy the following condition:

$$C_2 \geq C_1\frac{4b_1(1-H_0)}{a_1^2}$$

(6)

3 Design Steps and Example

Step 1. Decide pass-band dc gain:

Pass-band dc gain provides scalable output for the DAC output. Taking PCM1754 for an example, the maximum single-ended analog output is 1.414 Vrms. If a 2-Vrms output from the DRV6xx post-filter is desired, the pass-band gain must be set to 1.414 V/V, or 3 dB. Thus:

$$H_o = -\frac{R_2}{R_1} = -1.414$$

(7)

Step 2. Choose a suitable value for C1:

The recommended value for C1 for DRV6xx is from 15 pF to 220 pF. Select 100 pF for C1; C2 can be selected according to Equation 6:

$$C_2 \geq C_1\frac{4b_1(1 - A_0)}{a_1^2} = 483\text{ pF}$$

(8)

Choose standard value 560 pF for C2.

Step 3. Choose cutoff frequency according to desired application:

The Blu-ray™ DVD players require the audio frequency response to be within ±0.1 dB between 20 Hz and 20 kHz. Thus, the cutoff frequency (–3-dB point) is set at 54 kHz, according to Equation 1, resulting in an attenuation of only 0.08 dB at 20 kHz.

$$f_c = 54\text{ kHz}$$

(9)

Step 4. Calculating resistance value:

Using the selected values of C1, C2, Fc, and dc gain Ho, resistors R1, R2, and R3 can be calculated according to Equation 5. The equations have two possible solutions, providing two groups of results. In this example:

$$\text{Solution 1} = \begin{pmatrix} R_1 = 9.27\ k\Omega \\ R_2 = 13.108\ k\Omega \\ R_3 = 11.834\ k\Omega \end{pmatrix} \text{ and } \text{Solution 2} = \begin{pmatrix} R_1 = 20.203\ k\Omega \\ R_2 = 28.567\ k\Omega \\ R_3 = 5.43\ k\Omega \end{pmatrix} \quad (10)$$

Input resistor R1 must be larger than 10 kΩ for a good, low-frequency response, Solution 2 satisfies this condition. Choose standard values for Solution 2:

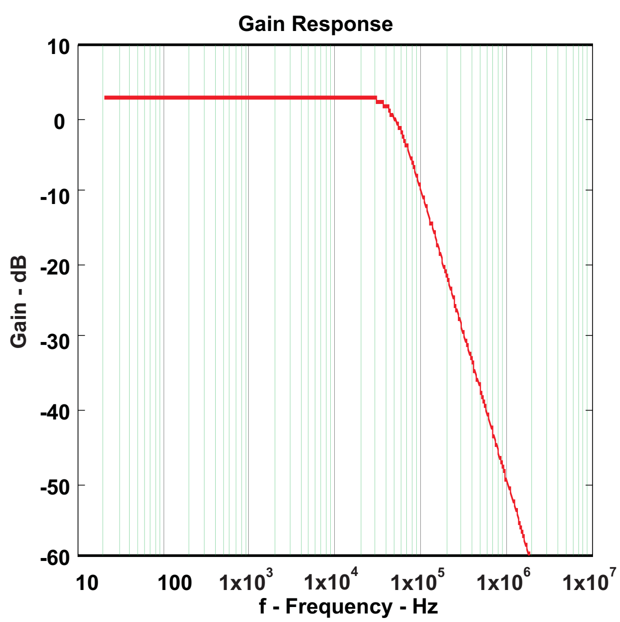
$$\text{Solution} = \begin{pmatrix} R_1 = 20\ k\Omega \\ R_2 = 28\ k\Omega \\ R_3 = 5.49\ k\Omega \end{pmatrix} \quad (11)$$

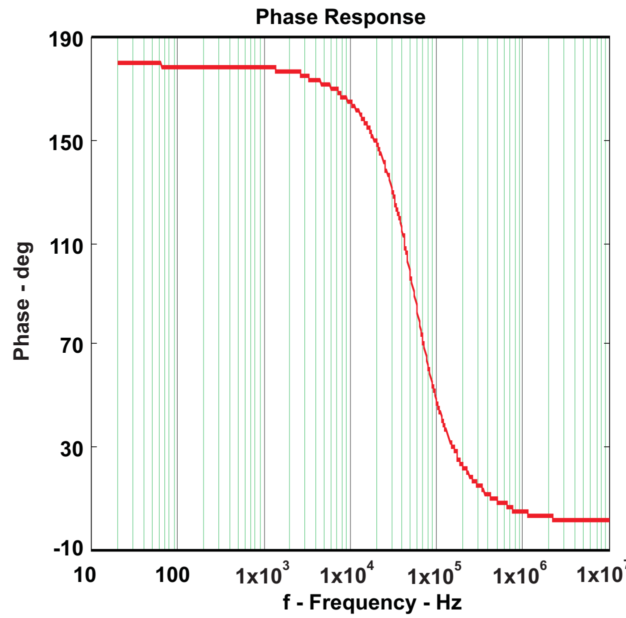
Step 5. Final result and gain and phase response curve:

The final result for the given design specification is:

$$\text{Final Results} = \begin{pmatrix} C_1 = 100\ pF \\ C_2 = 560\ pF \\ R_1 = 20\ k\Omega \\ R_2 = 28\ k\Omega \\ R_3 = 5.49\ k\Omega \end{pmatrix} \quad (12)$$

The gain and phase response curves follow.





4 Interfacing to Differential Output DAC

Figure 2 shows a circuit diagram for interfacing DRV6xx to a differential output DAC. Note that symmetry is required for better performance and ease of design. The external component values are exactly the same as that derived from the single-ended input circuit previously discussed.

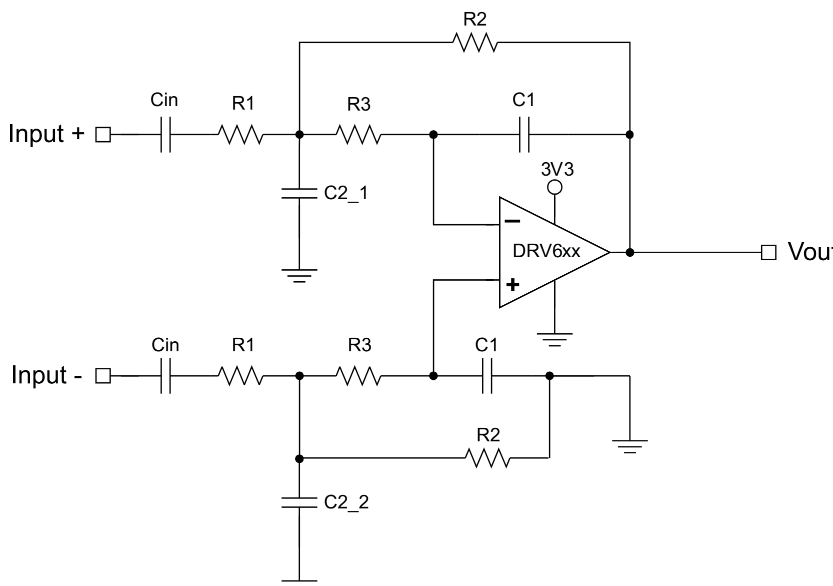


Figure 2. Circuit for Interfacing to Differential Output DAC

C2_1 and C2_2 can be combined into a single capacitor across the differential input node as shown in Figure 3. The capacitance of C2_3 is the same as the value of C2_1 and C2_2 in series (half of C2_1).

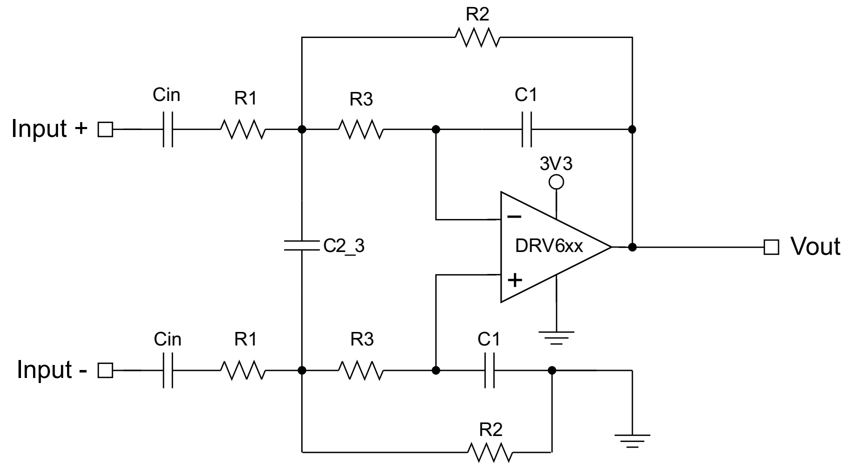


Figure 3. Simplified Circuit for Interface to Differential Output DAC

5 Reference Circuit for 2-Vrms Output Application

The Texas Instruments PCM1754 and PCM1789 are widely used as line-out DACs in many audio applications. The PCM1754 is a single-ended output device and the PCM1789 output is a differential output device. This section provides the reference circuits and parameters for using the DRV6xx as a post-filter to achieve 2-Vrms output.

5.1 Interfacing DRV6xx to PCM1754

Figure 4 shows DRV6xx interfacing with the PCM1754. The parameters are listed in Table 2.

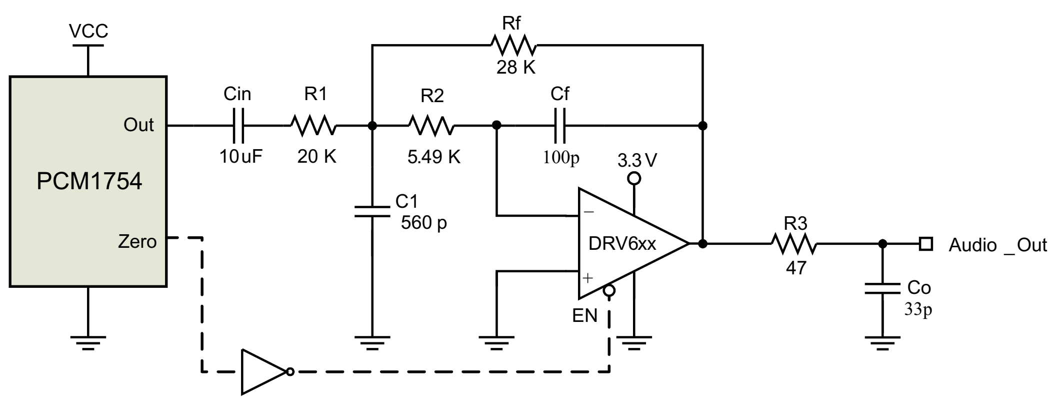


Figure 4. Interfacing DRV6xx to PCM1754

Table 2. Parameters for PCM1754 2Vrms Output Circuit

Gain, db	Gain, V/V	Output	High Pass	Low Pass	Cin	C1	Cf	R1	R2	Rf	R3	Co
+3 dB	1.414 V/V	2 Vrms	<10 Hz	54 kHz	10 µF	560 pF	100 pF	20 kΩ	5.49 kΩ	28 kΩ	47 Ω	33 pF

5.2 Interfacing DRV6xx to PCM1789

Figure 5 shows DRV6xx interfacing with the PCM1789. The parameters are listed in Table 3.

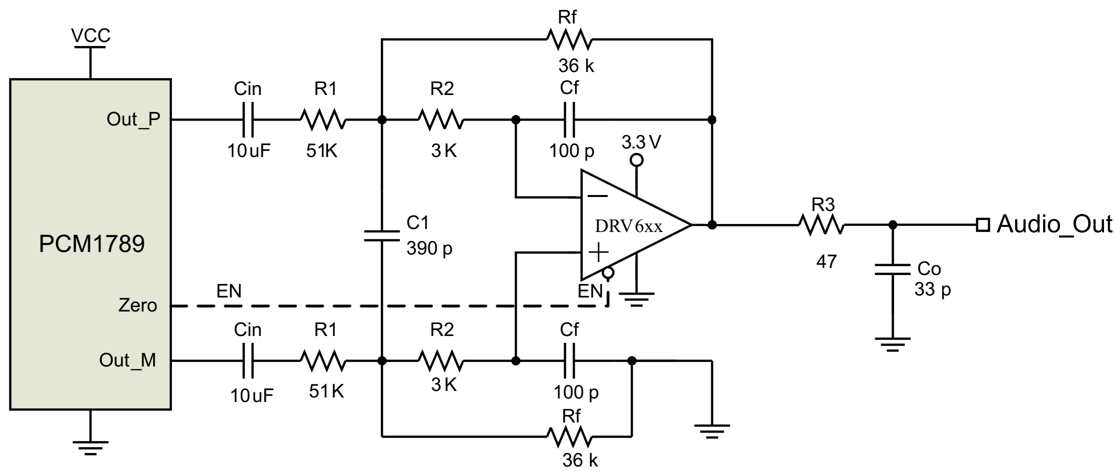


Figure 5. Interfacing DRV6xx to PCM1789

Table 3. Parameters for PCM1789 2Vrms Output Circuit

Gain, dB	Gain, V/V	Output	High Pass	Low Pass	Cin	C1	Cf	R1	R2	Rf	R3	Co
–3 dB	0.707 V/V	2 Vrms	<10 Hz	54 kHz	10 µF	390 pF	100 pF	51 kΩ	3 kΩ	36 kΩ	47 Ω	33 pF

6 Conclusion

This application report provides a detailed guide for Butterworth second-order, low-pass filter design based on DRV6xx devices. Examples of interfacing DRV6xx devices with Texas Instruments audio DACs are also provided.

7 References

1. *Op Amps For Everyone* design reference (SLOD006)
2. *Active Low-Pass Filter Design* application report (SLOA049)
3. *DRV603, DirectPath™, 3-Vrms Line Driver With Adjustable Gain* data sheet (SLOS617)
4. *DRV603EVM* user's guide (SLOU252)