

## Output Current Monitoring of High Voltage Class D Amplifiers

by Phillip Nanea and Paul Blanchard

### INTRODUCTION

Current information in a circuit can provide useful information about circuit health. Current monitoring circuits have been widely used in various fields of instrumentation for purposes of protection, compensation, and control. Common applications of current monitoring are battery monitoring systems, motor controls, overcurrent protection, and 4 mA to 20 mA systems.

Current monitoring may also be useful in commercial applications such as audio. One such application is monitoring

the output current of an audio amplifier through a speaker for sound quality compensation, as well as for protection purposes.

This application note focuses on a circuit for monitoring the output current of a speaker while operating in a high voltage range. The main components used in this circuit are a Class D amplifier, the [AD8479](#), and the [ADA4805-1](#).

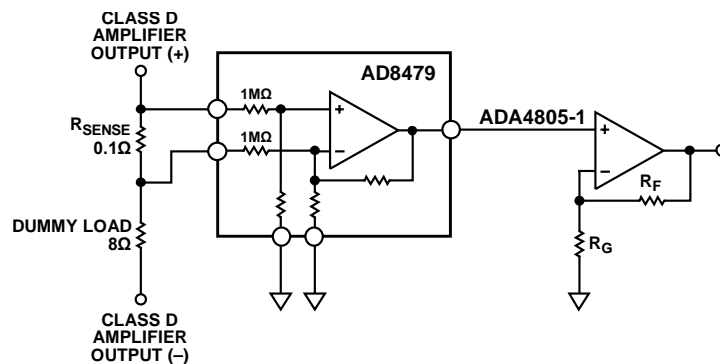


Figure 1. Current Monitoring Circuit Using the [AD8479](#) and the [ADA4805-1](#)

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**REVISION HISTORY**

1/16—Revision 0: Initial Version

## WHY A CLASS D AMPLIFIER?

An audio amplifier must reproduce an input audio signal in an efficient and low distortion manner. It should have a good frequency response over the 20 Hz to 20 kHz audio frequency range to reproduce sound and music faithfully. Audio amplifiers may need to provide output power as small as milliwatts for personal music players and headphones to up to hundreds of watts for powerful home and commercial sound systems, such as theaters, auditoriums, and outdoor sound systems.

Audio amplifiers have several classes: Class A, Class AB, Class B, and Class D. Class D amplifiers are the most power efficient in comparison with other classes, and these amplifiers can provide a high output power drive. Some commercial Class D amplifiers have power capabilities of 1500 W per channel to 6000 W per channel.

Class D amplifiers can be described simply as switching amplifiers or pulse-width modulation (PWM) amplifiers. The signal flow for a basic Class D amplifier is shown in Figure 2.

Operation of a typical Class D amplifier starts with the comparator. A standard analog audio signal with a frequency typically from 20 Hz to 20 kHz is compared to a high frequency triangular waveform to produce the PWM signal. The PWM signal then drives the output transistor stage, creating a train of pulses that may be high in voltage. Finally, a low-pass filter retrieves the sinusoidal audio signal.

The current through the output transistors, when not switching, is zero, and the low on-state resistance reduces  $I^2R$  losses, significantly reducing the total power losses in the output stage. In this manner, high efficiency is achieved.

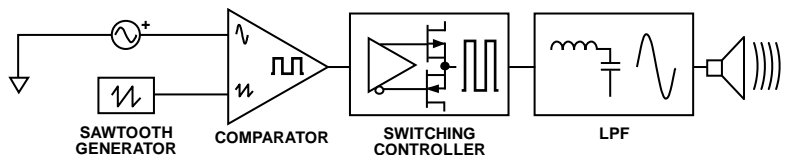


Figure 2. Signal Flow for a Basic Class D Amplifier

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## CURRENT MONITORING CIRCUIT

### CIRCUIT VALUE

Even with the high efficiency and high power operation advantages of Class D amplifiers, some techniques, such as using feedback and predistortion mechanisms, can still improve audio quality. Figure 4 shows a basic Class D amplifier using a feedback mechanism. In the feedback mechanism, the output signal, typically from the filter, is sent to an error correction block at the input. The error correction block may be fully analog or may employ digital processing to intentionally predistort the audio signal to correct the output imperfection and to improve the audio output quality. Apart from the inherent nonlinearity of the loudspeaker, this imperfection can be due to the tendency of the speaker to change impedance due to temperature and aging.

A current monitoring circuit can acquire the data to feed back for error correction. The challenge with choosing components for this purpose is that the devices must be robust enough to accept the high voltage pulses at the output of the audio amplifier. The AD8479 can address this requirement because it can operate even in the presence of high input common-mode voltages. The ADA4805-1 is also added to the circuit to provide a low offset, low noise analog-to-digital converter (ADC) driver.

### CIRCUIT COMPONENTS

The AD8479 is a precision difference amplifier that accurately measures differential signal in the presence of high common-mode voltage of up to  $\pm 600$  V. The input common-mode voltage vs. output voltage plot shown in Figure 3 demonstrates this capability. It has low offset voltage, low offset voltage drift, low gain error drift, and excellent common-mode rejection ratio (CMRR) over a wide frequency range. In this application note, the AD8479 is configured as a high-side current sense amplifier that monitors the current of the Class D audio amplifier. The AD8479 also has a bandwidth of 130 kHz, which can cater to the bandwidth requirement of the audio application.

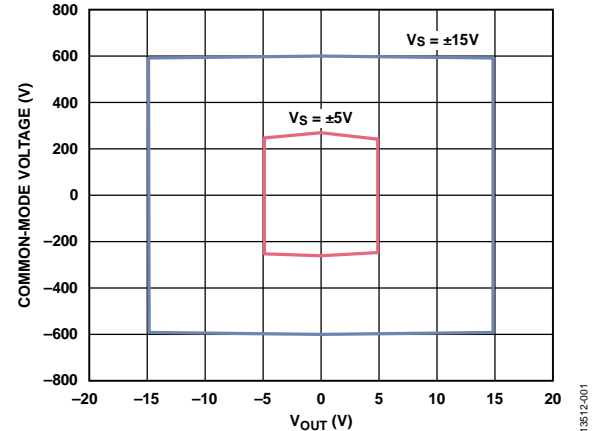


Figure 3. AD8479 Input Common-Mode Voltage vs. Output Voltage ( $V_{out}$ )

The ADA4805-1 is a low input offset voltage and low input offset voltage drift, rail-to-rail amplifier. The ADA4805-1 is set with a gain of 10 that produces an output voltage that is typically within the input voltage range of the next stage. The next stage typically uses a successive approximation register (SAR) ADC to process the audio signal.

The Class D amplifier used is the International Rectifier IRAUDAMP7S, which is a 25 W to 500 W scalable output power, Class D power amplifier. This amplifier is configured with a supply voltage of  $\pm 50$  V with 1 kHz sinusoidal output. Figure 1 shows the connections of the current monitoring circuit, where the  $0.1 \Omega$  sense resistor is connected between the Class D amplifier output and the  $8 \Omega$  dummy load in the high-side configuration.

The AD8479 output is fed to the input of the ADA4805-1, which acts as an ADC driver in a gain of 10. Keep the tolerance of the resistors low to avoid large offset drift of the circuit.

With the Class D amplifier used in this circuit, the current through the sense resistor ( $R_{sense}$ ) is 4.74 A, which generates a full-scale voltage of 475.71 mV peak. The common-mode voltage is 37.9 V peak.

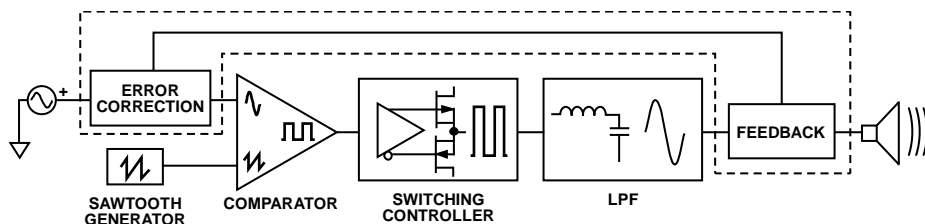


Figure 4. Basic Class D Amplifier Using a Feedback Mechanism

**MAJOR ERROR SOURCES**

CMRR is the ability of the device to reject the unwanted signal common to each input. Mathematically, it is the ratio of the change in common-mode gain to the differential gain. This parameter is usually one of the largest contributors of error in a circuit where a high common-mode voltage is present, especially when measuring a small differential signal. CMRR produces a corresponding output offset voltage error that contributes to the total error in the system.

The AD8479 is specified with 96 dB CMRR. Use the following equations to calculate the error contributed by the common-mode voltage:

$$Error (CMV \text{ in ppm of FS}) = \frac{CMV}{FS} \times 10^6$$

$$Error (CMV) = \frac{\frac{37.9 \text{ V}}{\frac{96 \text{ dB}}{20}}}{475.71 \text{ mV}} \times 10^6 = 1262 \text{ ppm of FS}$$

Another source of error is the offset voltage. The smaller the full-scale signal, the larger the error the offset voltage contributes. To calculate the offset voltage contribution, use the following equation:

$$Error (V_{os}) = (V_{os}/FS) \times 10^6 = \text{ppm of FS}$$

The AD8479 has an input offset voltage of 1 mV, which when converted to ppm contributes 2102 ppm of full scale.

$$Error (V_{os}) = (1 \text{ mV}/475.71 \text{ mV}) \times 10^6 = 2102 \text{ ppm of FS}$$

For the ADA4805-1, it is

$$Error (V_{os}) = 125 \mu\text{V} \times 10 \times 10^6 = 1250 \text{ ppm of FS}$$

The ADA4805-1 introduces a 125 μV offset voltage multiplied by a gain of 10, which results in a total error due to offset voltage of 3352 ppm of full scale (FS).

Moreover, the AD8479 has 0.02% FS gain error, as indicated in the data sheet, which means that an error of 200 ppm of FS is introduced to the circuit by the AD8479. To add gain error to the total error directly, calculate its equivalent ppm value using the following equation:

$$Error (Gain Error) = (Gain Error) \times 10^6 = \text{ppm of FS}$$

$$Error (Gain Error) = (0.02\%/100) \times 10^6 = 200 \text{ ppm of FS}$$

**ERROR BUDGET ANALYSIS SUMMARY**

Table 1 and Table 2 summarize the major error sources of the AD8479 and the ADA4805-1, respectively. The offset voltage of the AD8479 contributes the largest error, which is 2102 ppm of FS with a 37.9 V input common-mode voltage. The error contributed by the common-mode voltage is 1262 ppm of FS.

Although, here, the offset voltage contributes the largest error and the input common-mode voltage the second with a 37.9 V common-mode voltage and a 0.1 Ω sense resistor (see Figure 1), it is expected that the largest error contributor is the common-mode voltage. With a 250 V common-mode voltage, for example, the common-mode error contribution is 8329 ppm of FS, which is typical for high voltage Class D amplifiers. Furthermore, larger sense resistors cause larger voltage drops resulting in a higher full-scale voltage that eventually reduces all error contributions.

**Table 1. Major Error Sources for the AD8479**

Error Sources	AD8479	Error (ppm of FS)
Gain Error	0.02% FS	200
Common Mode	37.9V	1262
Offset Voltage	1 mV	2102

**Table 2. Major Error Source for the ADA4805-1**

Error Source	ADA4805-1	Error (ppm of FS)
Offset Voltage	125 μV × 10	1250

Figure 5 shows the test result responses of the current sense circuit. Figure 5 shows the input voltage at the AD8479, the output of the AD8479, and the gained up signal at the ADA4805-1 output. Around 4.74 A of current flows into the sense resistor and dummy load. The signal at the inverting input is approximately ±38 V and approximately ±500 mV appears at the output of the AD8479, which shows the capability of the AD8479 in measuring the differential signal in the presence of a high common-mode voltage.

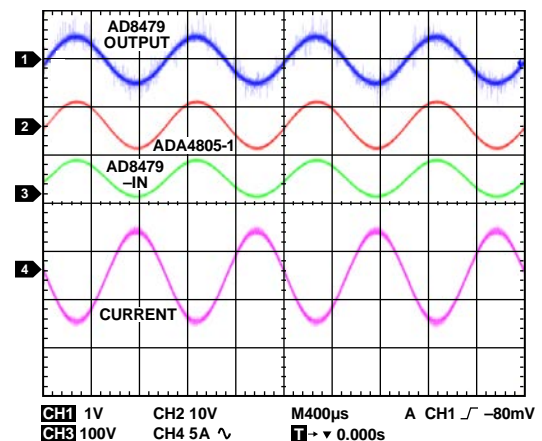


Figure 5. Measured Current and Voltages

Real-time monitoring requires not only high accuracy devices but also fast responses that can cope with sudden changes in the current of interest. It is important that the output signal changes as fast as the input signal changes, which requires a short time to appropriately interpret the electrical status of the loudspeaker as well as in a short-circuit event. Figure 6 shows the relationship of the input and the output responses vs. time, illustrating the rise time of the input signal and the AD8479 and the ADA4805-1 output.

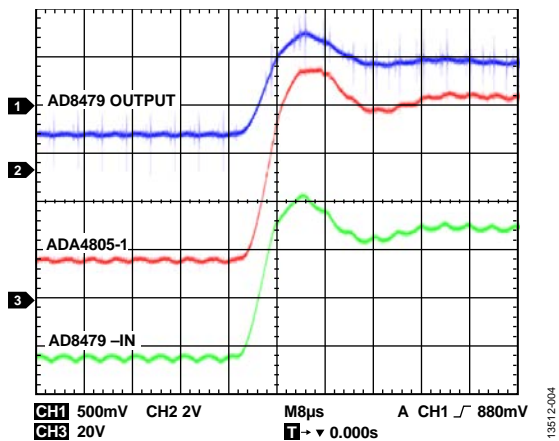


Figure 6. Measured Voltages Showing Phase Response

## CONCLUSION

The current monitoring circuit for a Class D audio amplifier requires robust and appropriate components to provide accurate measurements. The high input, common-mode voltage range of the AD8479 provides the necessary requirements for measuring the typical signal out of a Class D audio amplifier. In addition, the AD8479 and the ADA4805-1 have the sufficient bandwidth to cater to the operating requirements of the audio frequency band. These factors, along with excellent offset, gain, and CMRR specifications, make up a current monitoring circuit that provides high accuracy in this application.

For additional information, see the following:

- Gaalaas, Eric. “Class D Audio Amplifiers: What, Why, and How,” Analog Dialogue, 40-06, June 2006.
- MT-068 Tutorial, *Difference and Current Sense Amplifiers*. Analog Devices.