Circuits from the Lab® reference designs are engineered and tested for quick and easy system integration to help solve today's analog, mixed-signal, and RF design challenges. For more information and/or support, visit www.analog.com/CN0226.

Devices Connected/Referenced	
AD5116	Single-Channel, 64-Position, Push-Button, ±8% Resistor Tolerance, Nonvolatile Digital Potentiometer
SSM2375	Filterless, High Efficiency, Mono 3 W Class-D Audio Amplifier
AD8515	1.8 V Low Power CMOS Rail-to-Rail Input/Output Operational Amplifier
ADA4051-2	1.8 V, Micropower, Zero-Drift, Dual Rail-to-Rail Input/Output Op Amp

Portable Audio Amplifier with Volume Control

EVALUATION AND DESIGN SUPPORT

Circuit Evaluation Boards

CN-0226 Circuit Evaluation Board (EVAL-CN0226-EB1Z)

Design and Integration Files

Schematics, Layout Files, Bill of Materials

CIRCUIT FUNCTION AND BENEFITS

The circuit shown in Figure 1 is a complete low cost, low power, mono audio amplifier with volume control, glitch reduction, and a 3 W Class-D output driver.

The volume is controlled manually with a simple push-button interface to a 64-position digital potentiometer. An automatic store function retains the last volume setting, and an LED provides visual information of the maximum/minimum volume.

The SSM2375 Class-D driver amplifier provides up to 3 W output power into 3 Ω load, with 93% power efficiency at 5 V, built in pop and click suppression, and shutdown mode.

The circuit provides a preconditioning input stage, allowing compatibility with a wide range of audio input signals and can be powered with a cell battery.

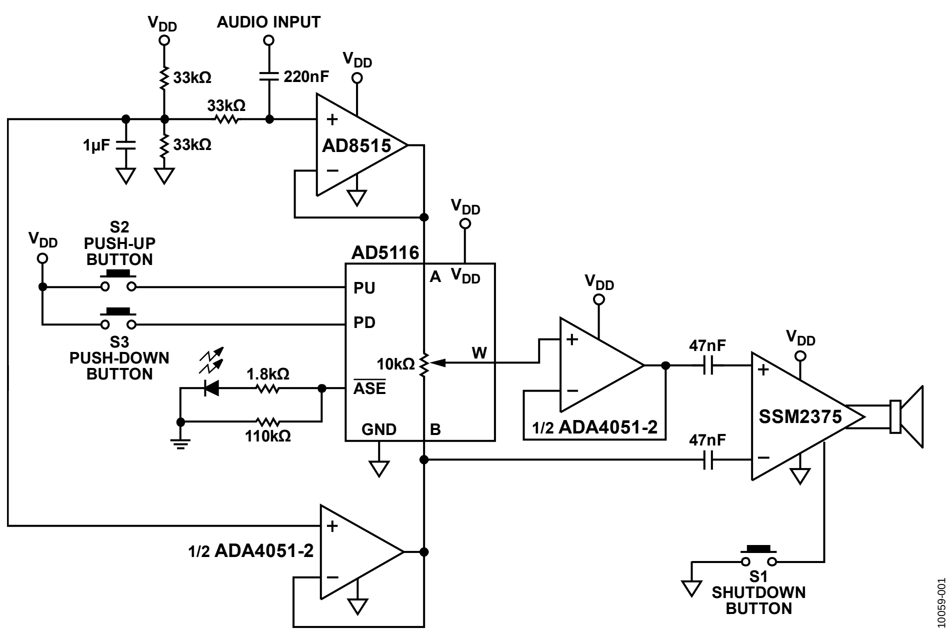

Figure 1. Audio Volume Control (Simplified Schematic: Decoupling and All Connections Not Shown)

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CIRCUIT DESCRIPTION

This circuit employs the 64-position AD5116 digital potentiometer in conjunction with the SSM2375 Class-D amplifier, dual ADA4051-2, and single AD8515 op amps, providing an ease of use circuit for low power and/or portable applications.

The input signal is filtrated by a high-pass filter that removes any dc offset voltage and centers the signal between the supply rails. The high pass filter also improves the power supply rejection (PSR). A separate filter is provided for the $V_{DD}/2$ bias voltage, as shown in Figure 2.

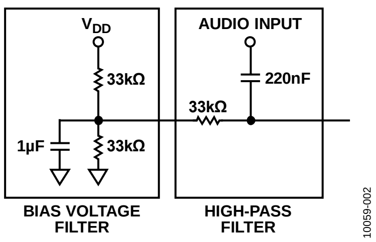

Figure 2. Input Filter Configuration

The filter formed by the 1 µF capacitor and the 33 kΩ divider resistors has a cutoff frequency of approximately 10 Hz. The high pass filter formed by the 33 kΩ resistor and the 220 nF capacitor has a cutoff frequency of approximately 22 Hz.

The bias voltage filter rejects supply noise at 10 Hz and above.

The AD5116 is configured in the potentiometer mode, thereby attenuating the audio input signal and is available in 80 kΩ, 10 kΩ, and 5 kΩ resistance values. Selecting the resistance represents a trade-off between linearity, noise, bandwidth, and total harmonic distortion (THD) performance. The 10 kΩ option was chosen for the circuit in Figure 1, although the 5 kΩ option yields a slight reduction in noise.

The dual AD8515 is a low cost, low power, rail-to-rail, input/output operational amplifier and is used to buffer the audio signal and drives the A terminal of the AD5116.

One-half of the ADA4051-2 op amp provides the low impedance $V_{DD}/2$ bias voltage to the B terminal of the AD5116. Setting the bias voltage at $V_{DD}/2$ provides optimum signal headroom and best THD performance.

The other half of the ADA4051-2 op amp is used to buffer the W terminal output of the AD5116.

The AD5116 provides an automatic store feature that ensures it retains the last volume position. The $\overline{\text{ASE}}$ pin has a double function when the automatic store is enabled. The pin indicates when the end of the resistance has been reached, which indicates the maximum/minimum volume. An LED is provided for visual information of the event.

The SSM2375 is a high efficiency Class-D amplifier that provides up to 3 W output power. The device provides a 12 dB gain with a built in pop and click suppression circuit that minimizes the transition glitches from the digital potentiometer.

A third push-button is provided on the board to shut down the audio output.

Figure 3 shows the THD + N performance of the circuit operating on a 5 V power supply with a 4 Ω + 15 µH load. Note that the THD + N increases at the 2 W output power level.

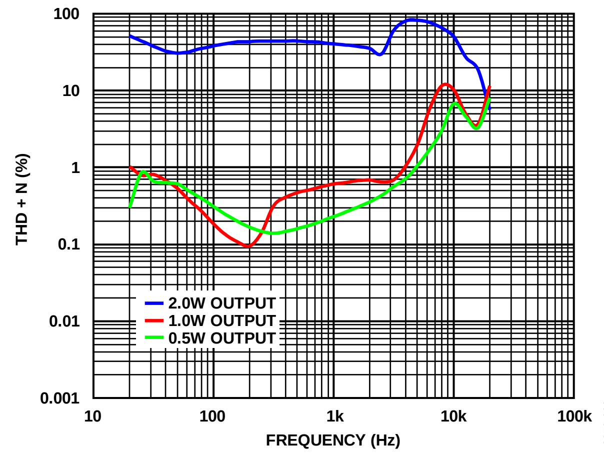

Figure 3. THD + N Performance of Circuit Using 5 V Power Supply, 4 Ω + 15 µH Load, Gain = 3 dB

Audio Input Signal Level Calculation

The SSM2375 output power is given by

$$Output\ Power\ (\text{W}) = \frac{(IN \times GAIN)^2}{R_{LOAD}}$$

where:
IN is the rms input voltage or $V_{PEAK}/\sqrt{2}$.
R_{LOAD} is the speaker impedance.
GAIN is the linear gain, by default 1.4125 (3 dB).

The SSM2375 gain can be set from 0 dB to 12 dB in 3 dB steps, as shown in Table 1.

Table 1. SSM2375 Gain Configurations

Gain Setting (dB)	GAIN Pin Configuration
12	Tie to VDD through 47 kΩ resistor
9	Tie to GND through 47 kΩ resistor
6	Tie to VDD
3	Open
0	Tie to GND

Optimum layout, grounding, and decoupling techniques must be utilized to achieve the desired performance (see the MT-031 and MT-101 tutorials). As a minimum, a 4-layer printed circuit board (PCB) must be used with one ground plane layer, one power plane layer, and two signal layers.

A complete design support package including schematic, layout, assembly, and bill of materials (BOM) is available at www.analog.com/CN0226-DesignSupport.

COMMON VARIATIONS

The circuit can be configured for ultralow power operation. If the circuit is used in a low power system, all three op amps can be replaced with the quad AD8508, which provides a very low supply current of 20 µA per amplifier and allows full functionality at a supply of 2.5 V.

It is also possible to externally implement an automatic shutdown to improve the attenuation at minimum volume using a D-type flip-flop, as shown in Figure 4.

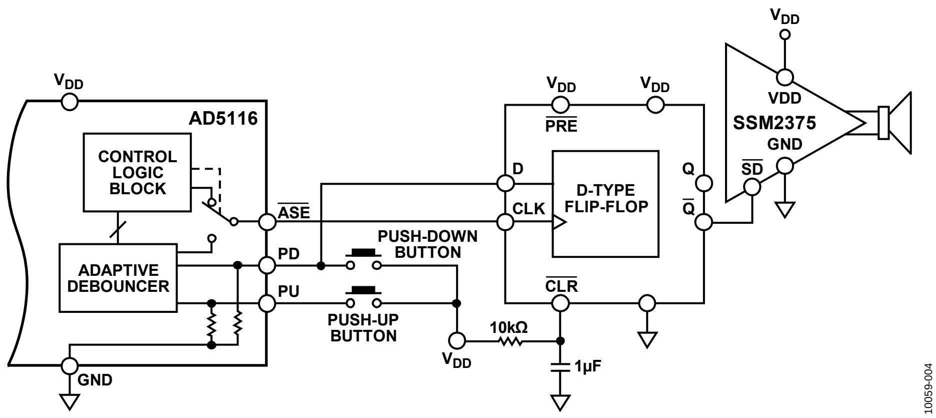

Figure 4. Automatic Shutdown Mode

CIRCUIT EVALUATION AND TEST

The circuit is tested using standard audio test equipment and methods.

Equipment Needed

The following equipment is required:

- EVAL-CN0226-EB1Z evaluation board
- DC power supply (2.7 V to 5.5 V)
- Audio Precision 2700 series audio analyzer or equivalent
- Audio Precision AUX-0025 filter or equivalent

Functional Block Diagram

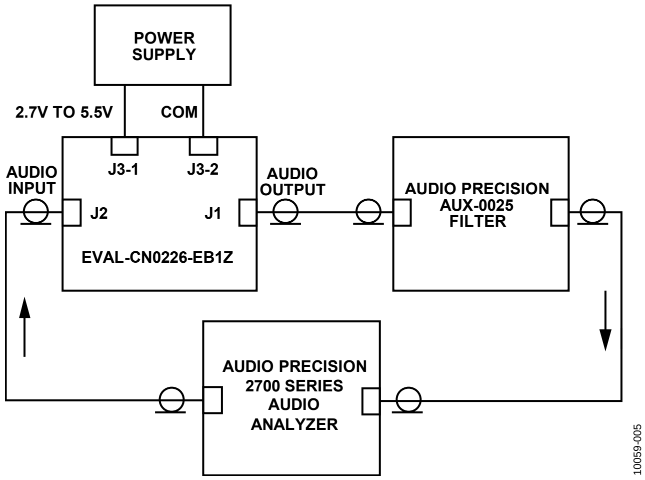

Figure 5. Test Setup Functional Diagram

Setup and Test

Connect the equipment as shown in Figure 5. Connect the power supply to the EVAL-CN0226-EB1Z board.

Use standard audio test methods to make the required measurements.

Figure 6 shows a photograph of the EVAL-CN0226-EB1Z board.

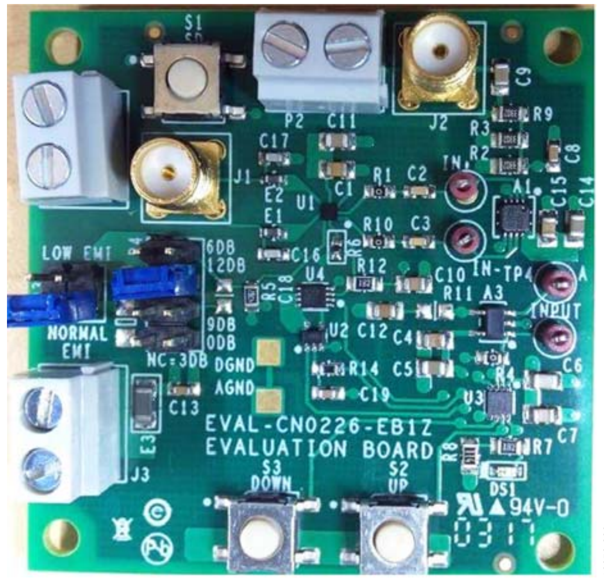

Figure 6. Photo of EVAL-CN0226-EB1Z

LEARN MORE

CN-0226 Design Support Package: www.analog.com/CN0226-DesignSupport

MT-031 Tutorial. *Grounding Data Converters and Solving the Mystery of "AGND" and "DGND".* Analog Devices.

MT-091 Tutorial. *Digital Potentiometers.* Analog Devices.

MT-101 Tutorial. *Decoupling Techniques.* Analog Devices.

Kitchin, Charles. AN-581 Application Note. *Biasing and Decoupling Op Amps in Single Supply Applications.* Analog Devices.

Usach Merino, Miguel. *Insight into digiPOT Specifications and Architecture Enhances AC Performance.* Analog Dialogue, (Volume 45, August 2011), Analog Devices.

Data Sheets and Evaluation Boards

CN-0226 Evaluation Board (EVAL-CN0226-EB1Z)

AD5116 Data Sheet

SSM2375 Data Sheet

AD8515 Data Sheet

ADA4051-2 Data Sheet

REVISION HISTORY

4/2017—Revision 0: Initial Version

CN10059-0-4/17(0)