

Measuring Class-D Amplifiers for Audio Speaker Overstress Testing

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Audio Power Amplifiers

ABSTRACT

This application report presents the results of an experiment conducted to demonstrate how to address the two most common concerns regarding speaker damage when using Class-D amplifiers.

1 Considerations for Audio Speakers

Determining if audio speaker limitations are violated can be challenging when using Class-D amplifiers. To obtain valid results, it is necessary to carefully analyze and interpret the switching behavior of the output signals. Filter-free Class-D amplifiers further complicate measurement because they do not require an output filter and the speaker can be connected directly to the amplifier output terminals.

The following information explains the methods to obtain the correct data for determining if a speaker's limitations will be exceeded.

1.1 Speaker Damage

An audio speaker can be damaged in three basic ways.

1. Exceeding the voltage rating in the audio frequency band.
2. Exceeding the speaker's power rating across the entire frequency spectrum.
3. Large dc currents through the speaker.

1.2 Speaker Modeling

An audio speaker is typically specified by a dc resistance. For example, *This is an 8-Ω speaker or That one is 4 Ω*. Whereas the speaker is generally modeled as a resistance, inductance and capacitance also must be considered. This inductance and capacitance helps to improve efficiency and to function as a small filter, similar to adding discrete components in front of the speaker to form an LC filter.

Another key characteristic of speakers is the impedance curve over frequency. As frequency increases, the impedance of the speaker increases rapidly due to the inductance of the voice coil. [Figure 1](#) shows that the impedance at 100 kHz is three times larger than at 20 kHz.

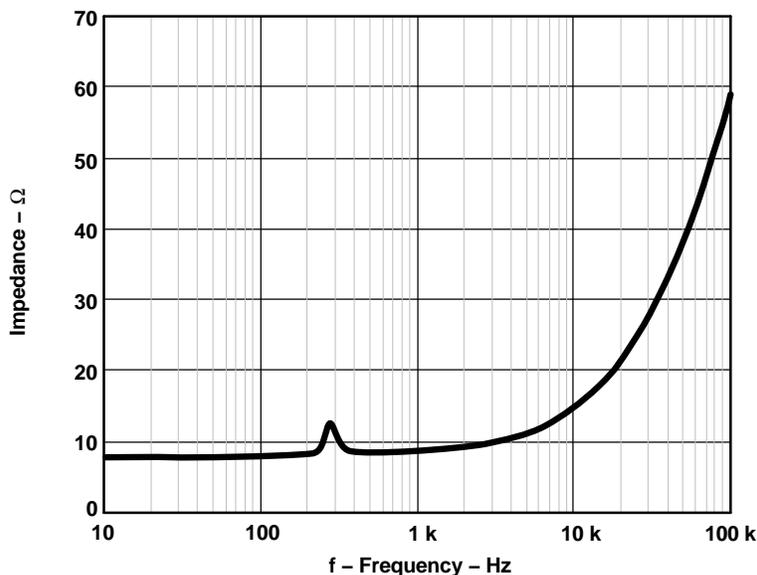


Figure 1. Example Impedance Curve for an 8-Ω Speaker

To better understand the effect of the inductance and capacitance within the speaker, consider the basic Class-D amplifier discussed in the following section.

1.3 Class-D Amplifiers and Your Speaker

Class-D amplifiers, also known as switching amplifiers, benefit from increased efficiency and thermal performance due to the output devices operating in either the saturation or cutoff region of their characteristic curve.

Classical Class-D operation (see [Figure 2](#)) involves the creation of two states in the differential output voltage. The two outputs are 180 degrees out of phase with one another, which creates a differential output that is either at +VCC or -VCC.

One of the major drawbacks in the past to this type of architecture being used as an audio amplifier was the cost and size associated with the external components (inductors and capacitors) that were required to make a low-pass filter for filtering the outputs. This was necessary due to the large peak to average current through the load (see [Figure 2](#)). This large current ripple required larger components with which to make the filter and remove the energy at higher frequencies associated with switching.

To solve this problem, Texas Instruments developed a filter-free Class-D architecture which employs a different switching scheme to create the differential output voltage. With this architecture, the output signals are *in-phase*, which creates a differential output voltage that is either +VCC, -VCC, or 0 V. The addition of the third state has the impact of reducing the peak to average current through the load (see [Figure 3](#)).

This reduction in current allows smaller inductance and capacitance to provide the same filtering required from the large components that are necessary with classical Class-D architectures. In fact, the values are reduced to the point that the parasitic values inside the speaker are sufficient to provide the filtering. This allows the user to remove the external components once needed or use small values for filtering.

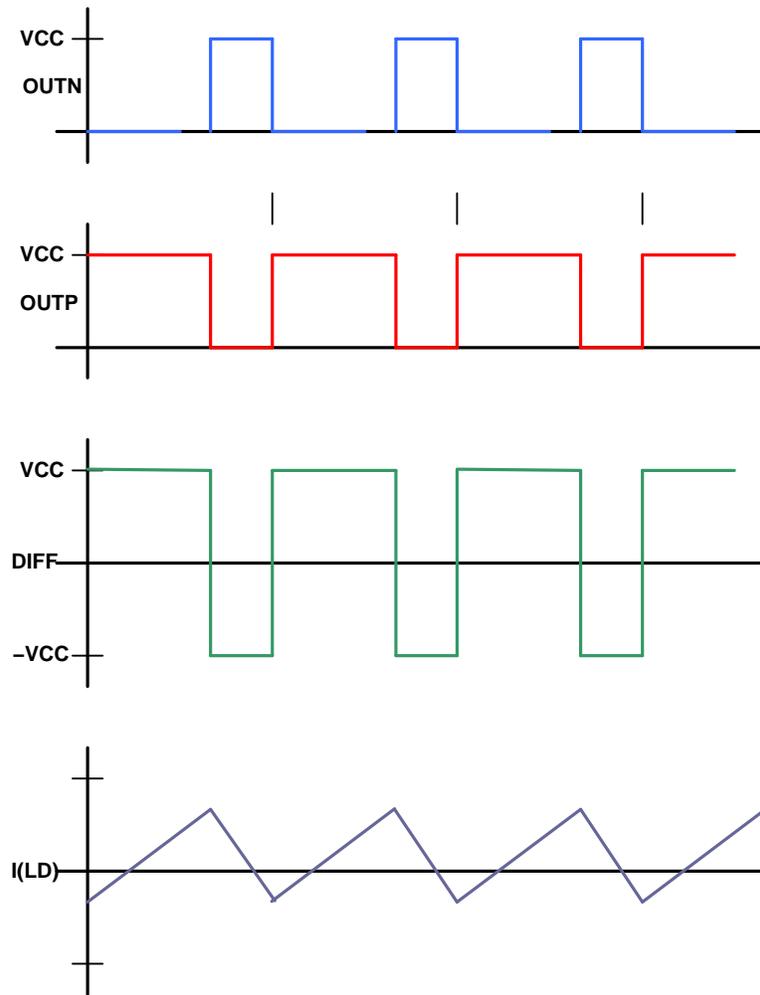


Figure 2. Classical Class-D Operation

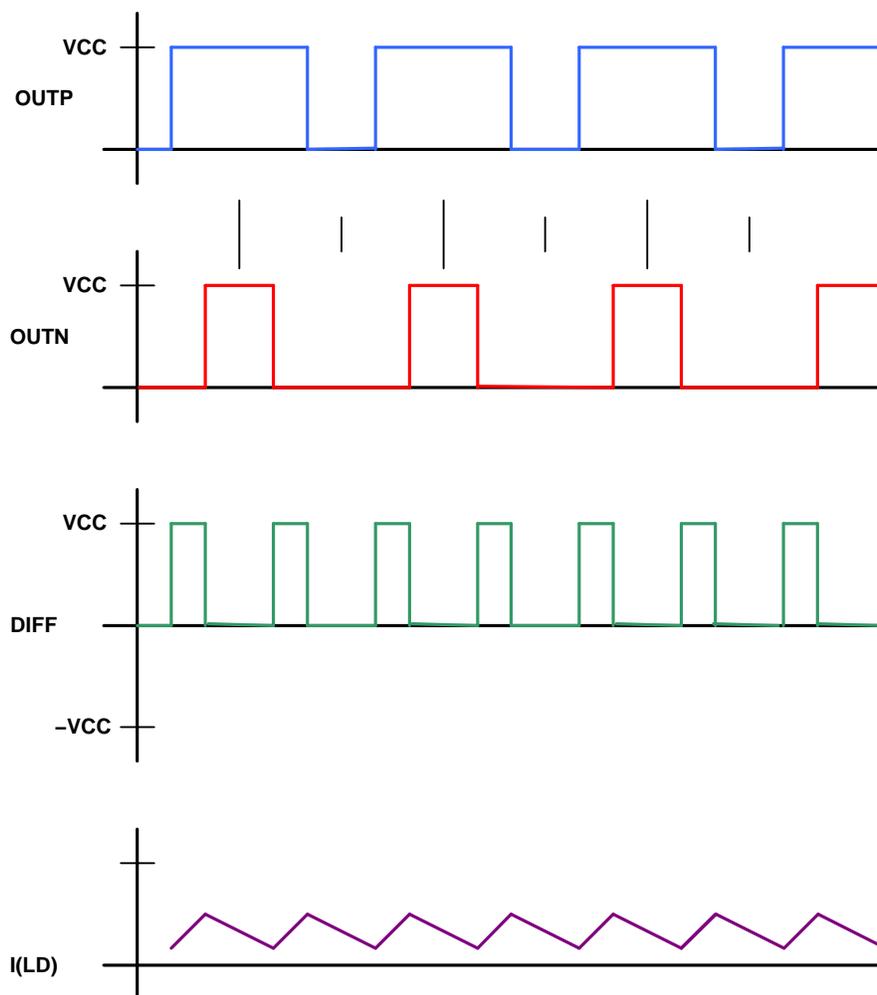


Figure 3. Filter-Free Class-D Operation

1.4 *But Does It Really Work?*

The preceding discussion explains some of the theory behind the speaker internals. But does it really work that way? This section details the measurements taken during the experiment to demonstrate the behavior of the Class-D amplifier and speaker.

1.5 Experiment Setup

The test setup used for this experiment is shown in [Figure 4](#).

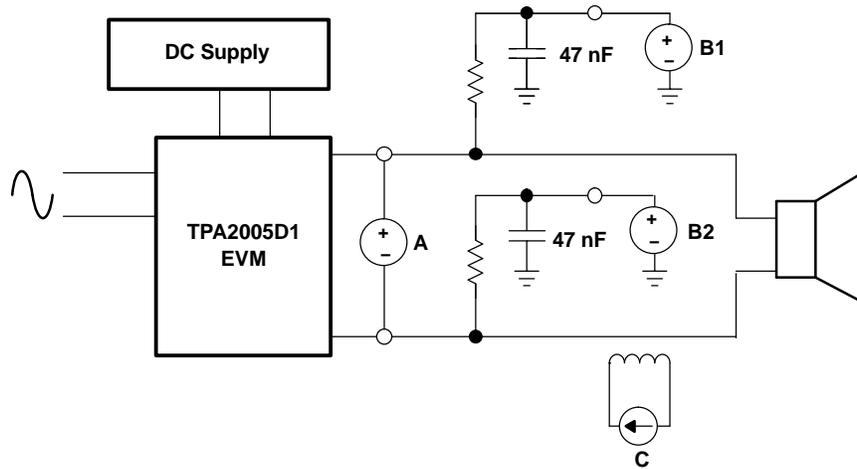


Figure 4. Experimental Test Setup

A 5-Vdc supply along with an 8- Ω speaker for the load was used. In order to make the proper measurement of the output voltage, care must be taken to obtain accurate results. Because the output audio signal is differential, the measurement can be made in two different ways. Both methods were used during this experiment.

The first method involves using a differential probe. This is a special probe that allows the connection of one probe to the positive output and the other probe to the negative output. The differential probe measurement is demonstrated with Measurement A in [Figure 4](#). Measuring the differential voltage by using a regular voltage probe requires the use of the second method. This method involves using two probes, one on each output with the probe ground connected to signal ground. The measurements are shown with Measurements B1 and B2 in [Figure 4](#). The signals then can be subtracted using the mathematical functions on the oscilloscope.

In addition to the two voltages, measurement of the current is required. For this experiment, the current was measured using a current probe connected to the oscilloscope.

The amplifier was driven with a 1-kHz input signal that provided 2 V_{rms} of output voltage. The output voltage and current waveforms were captured and the results from the measurements are shown in [Figure 5](#).

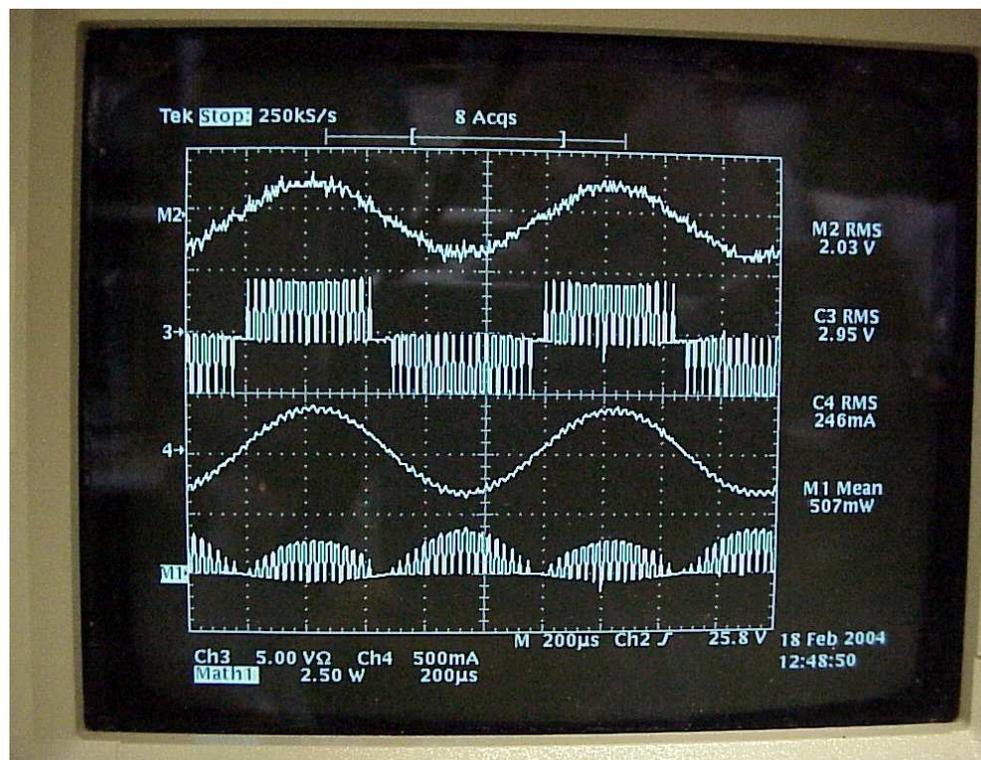


Figure 5. Waveform Results From the Experiment

1.6 Interpreting the Experiment Results

The waveforms obtained from the experiment and shown in [Figure 5](#) help to demonstrate that damage to the speaker does not occur as a result of the Class-D audio waveforms.

Waveforms M2 and 3 both show the same differential output signal obtained using the different probe measurements described previously. Waveform M2 shows the differential output voltage that has been filtered using a 30-kHz, low-pass filter to show the voltage waveform in the audio band. The resulting waveform shows that it indeed has a 2-V_{rms} value. Waveform 3 shows the differential output voltage without any filtering. From this waveform, the measurement shows that there is ~3-V_{rms} value. This demonstrates that the difference in the voltages is contained in higher frequency components (above 30 kHz) of the output waveform. Speakers have a response that is proportional to $1/f^2$. Therefore, the higher the frequency, the more the response is decreased, which eliminates the first way previously listed as a basic cause of speaker damage.

The effect of the inductance and capacitance in the speaker can be shown by viewing the load current in Waveform 4 of [Figure 5](#). This is the unfiltered current waveform passing through the speaker. It appears as though it has been filtered, but this is due to the inductance and capacitance within the speaker. They function to reduce the high-frequency component of the current through the speaker. Note the small ripple on the current waveforms that shows higher frequency components are still present, but have been attenuated by the speaker. Therefore, when power is computed at these higher frequencies, a small current is used to determine the power dissipated in the speaker.

The last curve, M1, is the power calculated as the amplifier operates. This is the instantaneous power shown and represents $V \times I$ at each instant during operation. The waveform was generated using the mathematical functions of the oscilloscope and multiplying Waveforms 3 and 4. These waveforms represent the voltage and current seen by the speaker. The average power (see the second basic cause for speaker damage) is displayed as a measurement on the right side of the waveform. As is shown, the power measurement is only slightly larger than the audio power delivered, 0.5 W. Again, the reason for

this is that power is found from the voltage times current at a particular frequency. Because the speaker has parasitic inductance and capacitance, the current at higher frequencies is small. This means that the power dissipated in the speaker at frequencies above the audio band is small compared to the power delivered in the audio frequency band. This small amount of power is dissipated in the form of heat in the speaker.

2 Summary

Performing this experiment demonstrates how to test for the two major causes of speaker damage (previously listed) when using Class-D amplifiers. At first glance, the amplifier may appear to violate the speaker specifications by measuring the unfiltered output voltage. However, the output voltage may actually meet the specifications, because only the audio frequency band needs to be considered. Speaker characteristics at high frequency allow customers to take advantage of efficient audio amplifiers using filter-free, Class-D technology and still operate their speakers within specifications.

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