Application Report

SLOA107 – April 2004

RC Filter Box for Class-D Output Power and THD+N Measurement

Audio Power Amplifiers

ABSTRACT

This application report describes how to use the Texas Instruments RC (resistor/ capacitor) filter box for measuring the RMS output power and THD+N (total harmonic distortion plus noise) of Texas Instruments' Class-D audio power amplifiers. It is to be used with standard measurement equipment like an oscilloscope and an Audio Precision (AP) analyzer. This report introduces the filter box, explains the calculation of the filter used, and most importantly, how to use the filter box when measuring output power and THD+N.

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Quick Start Setup

This section shows how to quickly set up the test circuit for the TPA3004D2 EVM with the RC filter box and an oscilloscope for output power measurement. Figure 1 shows the expected waveforms when passing a 1-kHz sine wave through the TPA3004D2 EVM (gain set to 2 V/V or 6 dB) and the RC filter box.

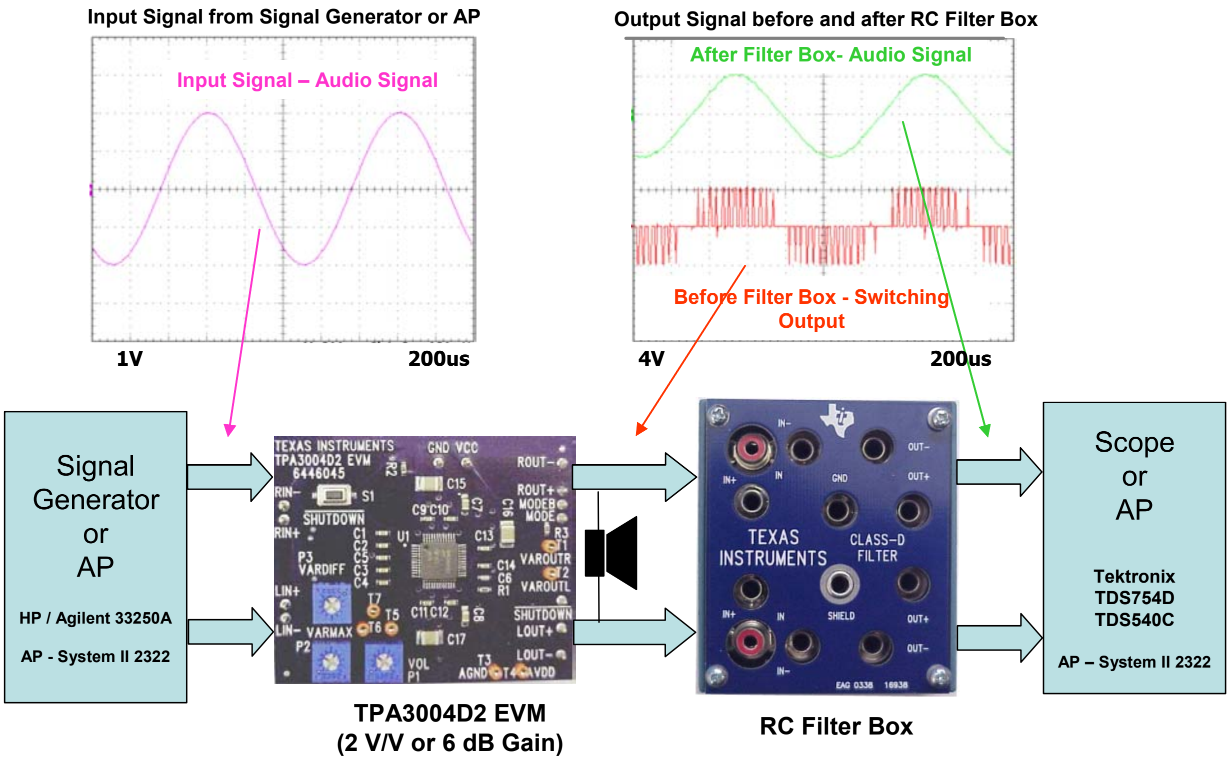

Figure 1. Filter Box Setup for Output Power Measurement

This setup clearly shows that by using the RC filter box to remove the high-frequency switching signal from the Class-D outputs, the output power level can be calculated using the oscilloscope voltage values, the load impedance, and the simple mathematics explained in this application report.

1 Introduction

Measuring the output power of typical linear amplifiers is generally a simple process. However, due to their switching nature, the same methods cannot be directly used when using Class-D amplifiers. In the case of the Class-D amplifier, the output must be low-pass filtered to allow for accurate measurements, due to the limitations of the measuring equipment. This is also true for measuring the total harmonic distortion plus noise (THD+N) together with an Audio Precision (AP) audio analyzer. This application report introduces a two-channel filter box that Texas Instruments (TI) developed to help audio engineers understand how to measure output power and THD+N performance.

This application report comprises the following four sections:

- Filter explanation (cutoff frequency, component values)
- Filter box
- How to use the filter box for measuring output power
- How to use the filter box with an AP analyzer for measuring THD+N

1.1 Why use a low-pass RC output filter with Class-D amplifiers?

Texas Instrument's range of Class-D audio power amplifier (APA) families (TPA2000D and TPA3000D) use a modulation scheme that does not always require an output filter for operation, but they do require some sort of low-pass filtering when making an output power measurement or a THD+N measurement. This is because the 250-kHz switching signal is seen as a common-mode voltage across the inputs of the audio measurement instrument. Typically, audio analyzing equipment has low common-mode rejection at 250 kHz, because the equipment is designed to work in the audio band. Although most audio analyzing instruments have internal filtering, they still have input amplifiers that cannot respond to the fast rising edges of the PWM signal. The purpose of the RC filter is to remove the 250-kHz switching component from the PWM output of a Class-D amplifier.

1.2 Output Power

Audio power amplifier design typically uses speakers with impedances from 3 Ω to 32 Ω. When calculating the power, the output voltage (V_O) is specified as an RMS value and the following equation is used:

$$P_O = \frac{\left[V_{O(RMS)}\right]^2}{R_L}$$

Where,

P_O = Output power

R_L = Load impedance

And,

$$V_{O(RMS)} = \frac{V_{O(P)}}{\sqrt{2}} \text{ and } V_{O(RMS)} = \frac{V_{O(PP)}}{2\sqrt{2}}$$

Where,

$V_{O(P)}$ = Peak voltage

$V_{O(PP)}$ = Peak-to-peak voltage

It is important to understand the relationships among peak output voltage ($V_{O(P)}$), peak-to-peak output voltage ($V_{O(PP)}$), and the RMS output voltage ($V_{O(RMS)}$) because these specific values are used when calculating the output power delivered to the load.

1.3 Total Harmonic Distortion Plus Noise (THD+N)

The typical THD+N measurement combines the effects of noise, distortion, and other undesired signals into one measurement and relates it (usually as a percentage) to the fundamental frequency. Ideally, only the fundamental test frequency of the sine-wave input is present at the output of the APA, which in practice is never the case. The THD+N measurement requires notching out the fundamental test frequency and measuring the RMS voltage (which includes unwanted harmonics and noise) across the audio band (which the AP does automatically) and then dividing that measured value by the fundamental test frequency value and expressing it as a percentage.

2 The Low-Pass RC Filter

This cutoff frequency of the RC filter was chosen to be approximately 30 kHz, because this is just outside the audio band and provides 20 dB/decade of attenuation for higher frequencies.

The cutoff frequency for a first order RC filter is:

$$f_O = \frac{1}{2\pi RC}$$

This formula assumes a filter cutoff frequency of approximately 30 kHz and a simple component selection, e.g., a 100-Ω resistor (R) and 0.047-µF capacitor (C). The resulting f_o was 33.86 kHz, and the circuit is shown in Figure 2.

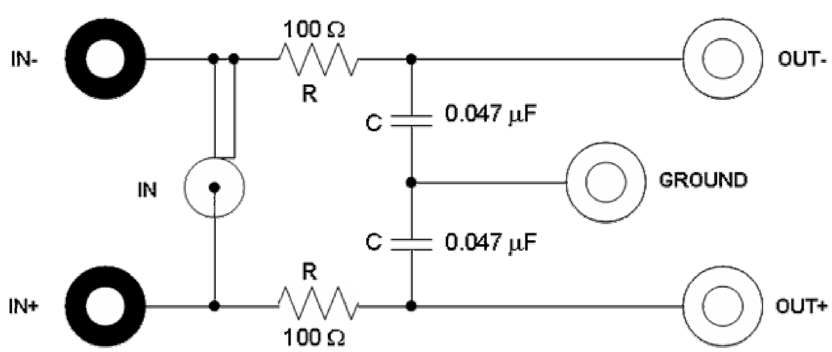

Figure 2. Schematic of the RC Low-Pass Filter for One Channel

NOTE: It is important that the signal generator, Class-D amplifier, filter box (GND), and oscilloscope or AP analyzer all be connected to the same ground in order to remove any common-mode voltage. Use the power supply ground for this purpose.

Section 3 illustrates how to physically use the board for an output power measurement.

3 The RC Filter Box

The RC filter box has two channels and was developed so that customers can simply set up their test and not have to build their own filter boards. Figure 3 shows the top and the inside of the box.

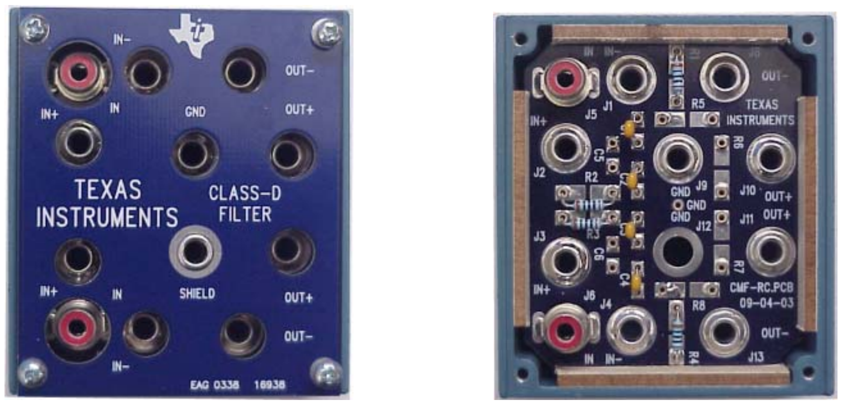

Figure 3. Top and Inside View of Texas Instruments RC Filter Box

As previously explained, the cutoff frequency of this filter was fixed at approximately 30 kHz, which effectively filters off the 250-kHz switching frequency and allows easy voltage reading from the oscilloscope. Because the SHIELD connector is the shielding for the entire box, connect it to a quiet ground at the supply and not to the same ground as the amplifier and the measurement equipment.

4 How to Use the RC Filter Box

The RC filter box can be used for output power measurement (with an oscilloscope) and THD+N (together with an AP analyzer). The box's design allows easy connection to the various measurement devices during the initial evaluation, prototype development, and final test. The following section discusses power measurement, and the subsequent section discusses how to use the filter box for THD+N measurement.

4.1 Output Power Measurements

The filter box must go after the load and before the oscilloscope. Once the test circuit has been correctly set up for either a mono or stereo measurement, and the output power for each channel is calculated using the peak voltage (read off the oscilloscope) and the known load impedance, the output power can be correctly calculated. Remember that output power in this application report is specified as RMS.

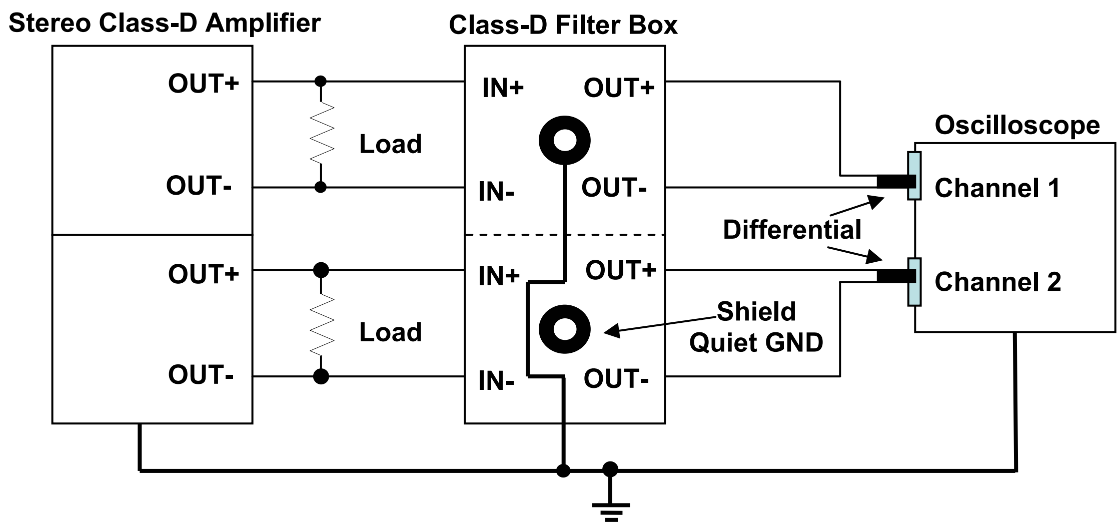

Figure 4. Stereo Class-D Amplifier and RC Filter Box for Output Power Measurement

NOTE: This circuit assumes differential probes at the oscilloscope. Another option is to use single-ended probes with the oscilloscope, and use a mathematics function to get the differential of both signals by subtracting the two signals. Alternatively, a simple RMS voltmeter can take the same output power measurement.

Example:
By taking one channel for the output power measurement, if the peak output signal voltage on the oscilloscope is 2 V and the load R_L is 8 Ω, then the RMS voltage is calculated as:

$$V_{O(RMS)} = \frac{V_{O(P)}}{\sqrt{2}} = 1.41V$$

And therefore,

$$P_O = \frac{\left[V_{O(RMS)}\right]^2}{R_L} = 250mW$$

Where,

P_O = Output power

R_L = Load impedance

4.2 THD+N Measurements

The setup for THD+N measurements is similar to the output power measurement, but this time, an AP audio analyzer is connected to the amplifier's inputs and the output of the filter as shown in Figure 5.

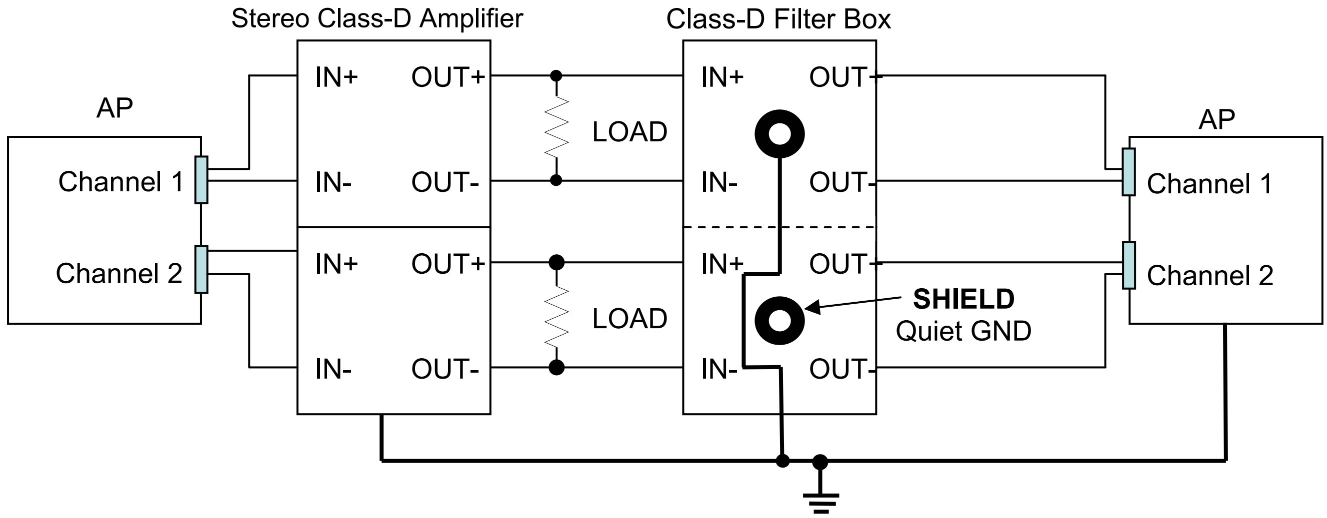

Figure 5. Stereo Class-D Amplifier and RC Filter Box for THD+N Measurement

The bandwidth is usually limited with filters in the analyzer to reduce the out-of-band noise; however, this also reduces relevant harmonics of the higher frequency signals. As mentioned previously, the filter box cutoff frequency is set to approximately 33 kHz for the THD+N measurement of the Class-D amplifier. This is because 2^{nd} and 3^{rd} harmonics typically contain the most energy and for a 10-kHz input signal, having the cutoff frequency at 33 kHz, provides an adequate representation of the THD+N. For higher frequencies, these harmonics are beyond the audible threshold of the human ear and are not a factor.

5 Conclusion

Measuring the specifications of a Class-D amplifier can be more challenging than a standard linear amplifier. TI developed the filter box as a simple but effective tool for audio engineers to calculate the output power and the THD+N of Class-D audio power amplifiers during the evaluation and prototyping phase. Because it is optimised for Class-D amplifiers, the TI RC filter box saves the engineer time and effort and allows simple calculation of the RMS output power into a known load and the kind of distortion levels a Class-D amplifier causes.

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