Application Report

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Out-of-Band Noise Measurement Issues for Audio Codecs

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ABSTRACT

This report discusses the phenomenon of out-of-band noise, and examines the results of the out-of-band noise measurements for audio codecs. Frequency spectrum measurements were done on the TLV320AIC33 to analyze the output out-of-band noise. FFTs were captured for the HPOUTs in various conditions to demonstrate the effects of filtering for measurement purposes.

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1 Out of Band Noise

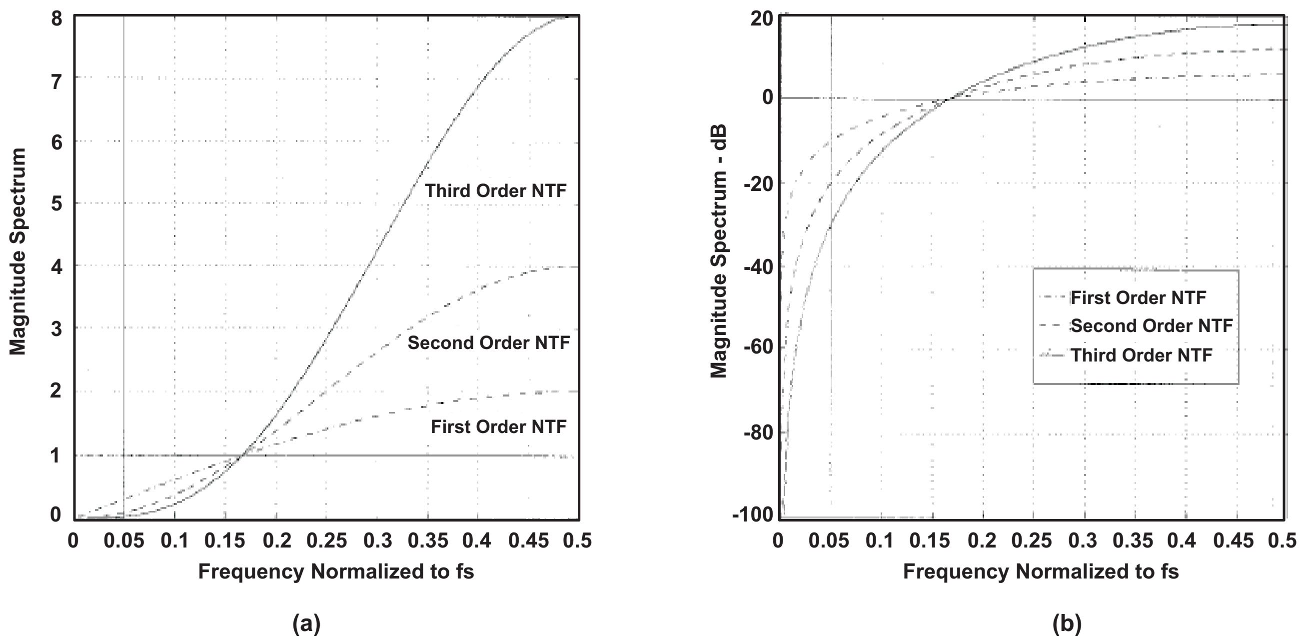
1.1 Definition

In audio systems, out-of-band noise is the noise contained in frequencies outside of the audio frequency band. The audio frequency band is defined as 20 Hz to 20 kHz. These are the minimum and maximum frequencies, respectively, that the human ear can discern. Frequencies below this range (sub-sonic) and above the range (super-sonic) are not perceived by humans. In addition, speaker response to frequencies above 20 kHz decreases proportionally to $1/f^2$. Due to this decreased response, a loudspeaker is not good at reproducing frequencies above 20 kHz.

1.2 Cause

Audio codecs are typically designed using a Sigma-Delta (Σ-Δ) architecture for the ADC's and DAC's. One of the characteristics of a Σ-Δ converter is that the Noise Transfer Function (NTF) is not flat, as with other types of data converters. The Σ-Δ modulator in these converters shifts quantization noise from the low frequencies (band of interest) to the high frequencies (out-of-band). This allows the codec device to achieve excellent noise performance (measured by SNR) while also exhibiting low power consumption at a low cost. To achieve signal-to-noise ratios above 95 dB without Σ-Δ modulation requires an expensive, power-hungry IC design

The drawback of Σ-Δ architecture is that it produces high-frequency artifacts that, while inaudible, can have other undesirable effects on a system. The level of this out-of-band noise is determined by a few main factors – namely the order of the modulator, the oversampling ratio, and any analog filtering after the modulator.



A I^2 NTF for the first, second, and third order Σ-Δ modulators; (a) magnitude spectra on a linear scale. For comparison, the oversampled PCM NTF, which has a unity gain is shown; (b) magnitude spectra in dB.

Figure 1. Effect of Σ-Δ Modulator Order on NTF (from Reference 1)

Figure 1 shows the effect of order on the noise transfer function of a Σ-Δ modulator. As shown, increasing the order of the modulator reduces in-band noise, while increasing out-of-band noise.

The oversampling ratio is set by the ratio of the internal sampling rate of the Σ-Δ modulator to the external sampling rate of the audio data. As oversampling ratio increases, in-band noise performance improves, while the out-of-band noise moves to higher frequencies.

For digital-to-analog converters (DACs), the out-of-band noise is reduced by on-chip analog filtering after the Σ-Δ modulator. A variety of different architectures are used, such as passive filtering, active filtering or switched-capacitor filtering. Passive filtering requires the lowest cost, area, and power consumption, but active or switched-capacitor filtering yields reduced out-of-band noise, but with a higher current consumption, cost, and silicon area.

Low-power audio codecs are designed with an optimal balance of low power, low cost, in-band noise performance, and out-of-band noise.

1.3 Effects

1.3.1 Effects on Measurement Equipment

When out-of-band noise is present in an audio system, measurement equipment used to test the system is adversely affected by the out-of-band noise. The reasons for these effects are slew-rate-limiting of the input stage, aliasing in an A/D converter, or improper scaling of an auto-ranging circuit. A standard measurement system used in audio engineering is the Audio Precision System Two. The effects of out-of-band noise on this system are described in a white paper (Reference 2).

1.3.2 Effects on Post-Processed Signals

When the a signal containing significant out-of-band noise is reprocessed by another component such as a PWM modulator in a Class-D amplifier, or another A/D converter, the out-of-band noise is modulated or aliased back into the audible band. For this reason, anti-aliasing low-pass filters are recommended between codec outputs and Class-D amplifier or A/D inputs. More details on the recommended filter values are provided in Section 4.

2 Out-of-band Noise Test Setup for TLV320AIC33

2.1 Test Setup

The measurements made in this report made use of the following setup and equipment:

- AIC33 EVM and USB-MOD EVM
  - Power from USB connection
  - I^2C™ control and I^2S data connections through PC GUI
- Rhode and Swartz spectrum analyzer FSEA 30
- Connection from EVM to analyzer using SMA cable
- Passive components (as required)

2.2 EVM Configuration

The AIC33 EVM was configured using the PC GUI as follows:

- DACL/R powered on routing through mixer
- DACL/R gain = 0 dB
- AC coupled outputs
- HPOUTL/R as single-ended
- HPOUTL/R connected to DACL/R respectively with gain = 0 dB
- HPOUTL/R output gain = 0 dB
- HPOUTL/R powered on

The commands used to setup the EVM in this configuration are found in Appendix A. They are written in the standard format for script files to facilitate importing them into the GUI.

3 Testing and Results

The test setup for the measurements included used an AIC33 EVM with the USB-MOD EVM. The EVM was connected to the PC and to the spectrum analyzer via SMA cable.

Figure 1 to Figure 6 show the results of the testing performed.

Note: The noise floor across the audio band is flat and the measurement was done starting at 1 kHz for measurement equipment purposes only. The high magnitude at 1 kHz that decreases to a low level around 7 kHz is a strictly a measurement issue and does not represent actual response of the codec in this range. The actual measurement is close to the level at 7 kHz.

3.1 Initial/Baseline Measurements

Two different baseline measurements were taken of the AIC33 HPOUTs to show the performance without any filtering or circuitry.

Figure 2 shows the output spectrum when the EVM has been powered up and configured as above in Section 2. No signal or music has been played through the DAC at this point. The frequency spectrum is shown as flat at a low level (approximately –98 dBm) since the modulator is not running.

Figure 3 shows the output spectrum after music or a signal is played through the DAC and then stopped (no input). The modulator is now turned on and the out of band noise spectrum is shown. The signal magnitude that is greater than 40 kHz–50 kHz shows the out of band noise characteristics of the device. The maximum value is approximately –42 dBm near 500 kHz. Note that frequency magnitude up to 40 kHz–50 kHz is low, which gives good performance in the audio band.

3.2 Filtered Measurements

By adding a filter in series with the outputs, measurements are made that accurately reflect the performance of the codec. The filter is designed as a RC, low-pass filter with a cutoff frequency of approximately 30 kHz. This allows the filter to attenuate the higher frequencies and allow the audio band frequencies to remain unaffected for good measurements.

For the purposes of the measurements taken in this report, two different RC filters were used. Filter 1 used 100-Ω and 47-nF components to achieve the proper filter. Filter 2 used 1 kΩ and 4.7 nF to achieve the same filter cutoff. The two different filters were used to determine the effect of the resistance on the output.

Figure 4 shows the addition of a 100-Ω resistor in series with the output to the analyzer. This shows the attenuation of the out-of-band noise due to the resistance. Notice that the maximum magnitude is reduced to approximately –52 dBm near 500 kHz.

Figure 5 shows the out-of-band noise spectrum with a low-pass, RC filter (100 Ω and 47 nF). The addition of the RC filter has reduced the out of band noise to approximately 15 dBm above the noise floor.

Figure 6 shows the addition of a 1-kΩ resistor in series with the output to the analyzer. This shows the attenuation of the out-of-band noise due to the resistance. The magnitude of the highest frequency is now approximately –69 dBm.

Figure 7 shows the out-of-band noise spectrum with a low-pass, RC filter (1 kΩ and 4.7 nF). The attenuation of the signal for this resistance and filter is increased compared to the results shown in Figure 4 and Figure 5. The higher resistance value RC filter has reduced the out-of-band noise below the noise floor.

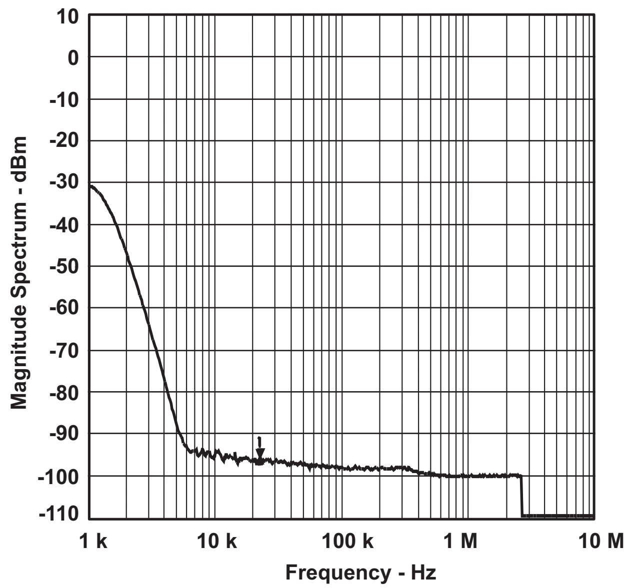


Figure 2. At Start-Up (no music yet played)

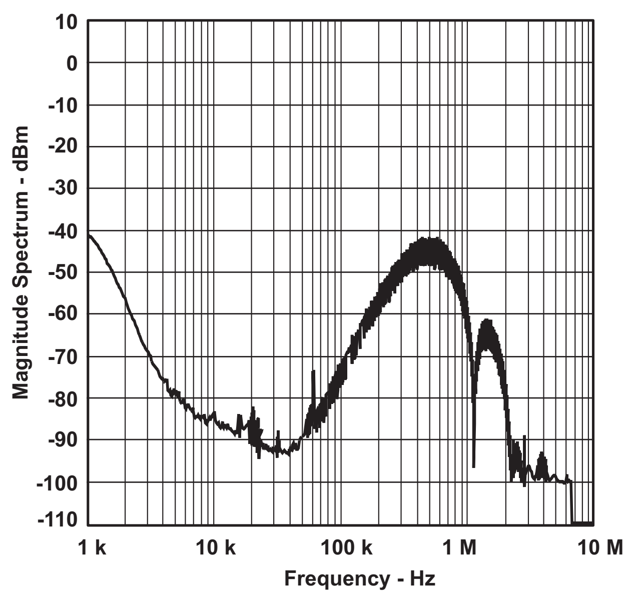


Figure 3. Output After Music is Played and Stopped

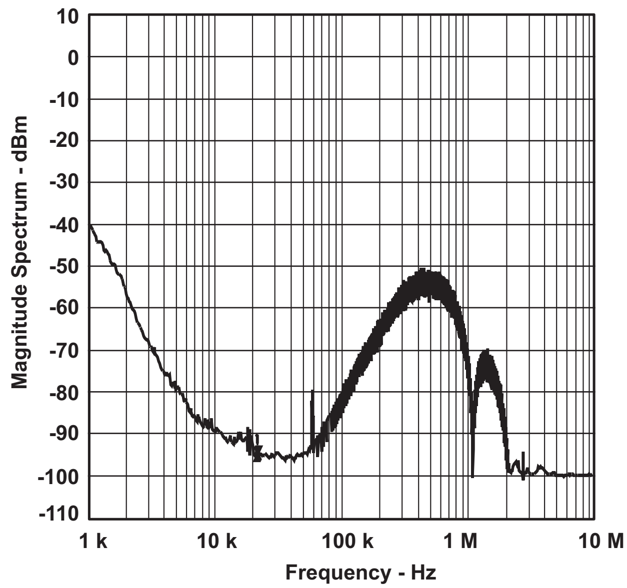


Figure 4. Output With 100 Ω in Series Between the Output and Analyzer

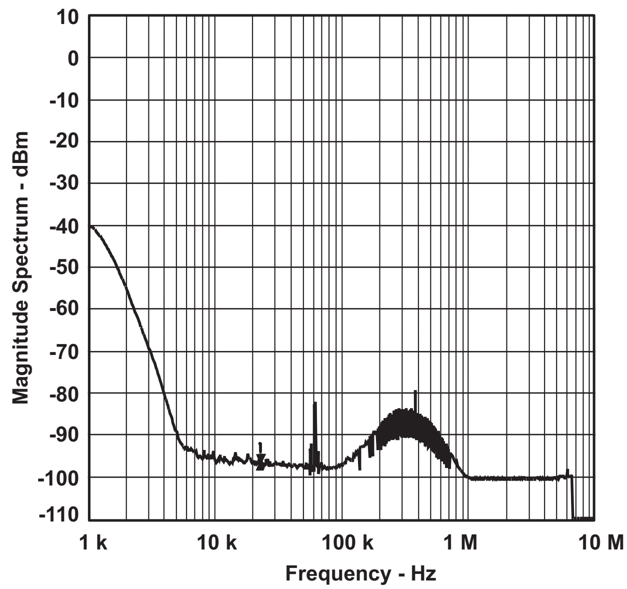


Figure 5. Output With RC Low-Pass Filter (100 Ω and 47 nF) in Series Between the Output and Analyzer

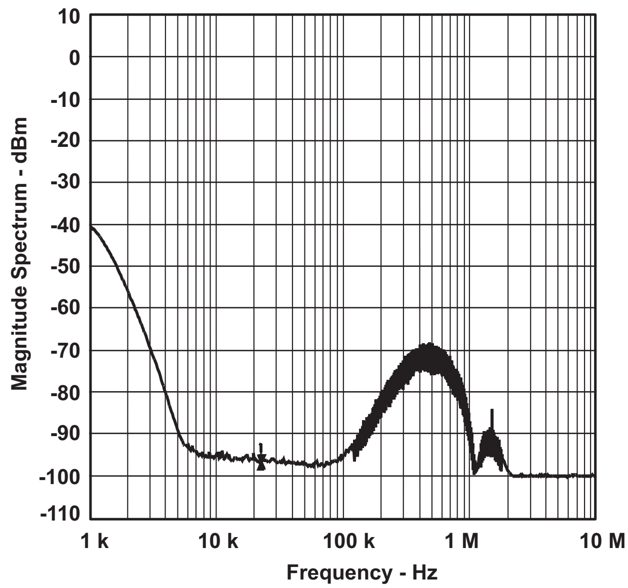


Figure 6. Output With 1 kΩ in Series Between the Output and Analyzer

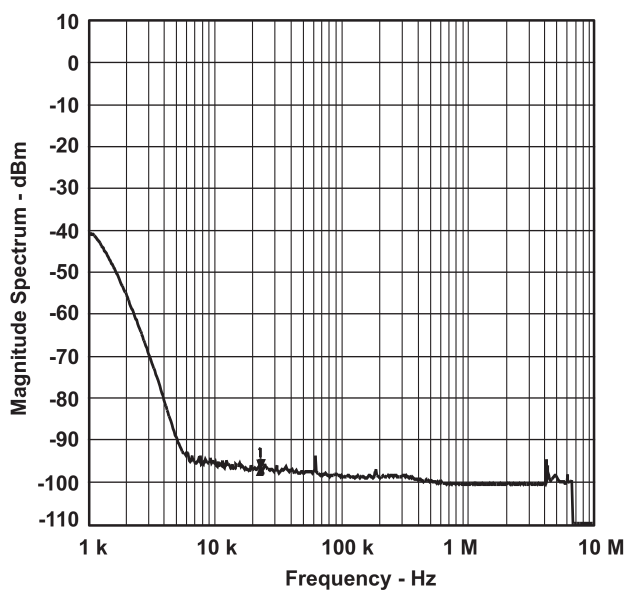


Figure 7. Output With RC Low-Pass Filter (1 kΩ and 4.7 nF) in Series Between the Output and Analyzer

4 Summary and Recommendations

This data, shows that a small, low-pass, RC filter dramatically reduces the out-of-band noise of delta-sigma audio codecs. Because the low-pass filter cutoff is above the audio band at approximately 30 kHz, the audio frequencies remains unchanged. The real performance of the codec should be measured without interference from the out-of-band noise.

For measuring the performance of the audio codec, the use of a small RC filter is recommended to reduce the out-of-band noise to prevent any interference with the measurement. The larger resistance value RC filter from above provides a little better attenuation of out-of-band noise and are used when measurement equipment has a high input impedance. For THD+N measurements, it may be better to use the smaller resistance RC filter to keep the distortion of the signal by the filter components to a minimum.

When connecting the outputs of the codec to another amplifier or low input impedance device, the smaller resistance value RC filter are used to prevent attenuation of the output signal. This filter should be used between the codec and Class-D audio amplifiers to prevent the audio amplifier from sounding noisy.

5 References

1. P. Aziz, H. Sorensen, J. Van Der Spiegel, *An Overview of Sigma-Delta Converters*, IEEE Signal Processing Magazine, pp. 61–84, January 1996.
2. Bruce Hofer, *Limitations in Making Audio Bandwidth Measurements in the Presence of Significant Out-of-Band Noise*, Audio Precision Inc., August 2005.

Appendix A Script for Testing Performed

The script shown below is used in the AIC33 GUI to setup the EVM to the same conditions used during the testing performed in this report. The text can be cut and pasted into the Command Buffer window on the Command Line Interface tab of the GUI or pasted into a text file and loaded the same as normal script files.

```
w 30 07 8A
w 30 25 C0
w 30 29 02
w 30 2B 00
w 30 0E C0
w 30 25 E0
w 30 26 10
w 30 33 05
w 30 41 05
w 30 2F 80
w 30 40 80
w 30 33 0D
w 30 41 0D
```

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