Testing DDX® Digital Amplifiers

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Last Updated 0/0/0000

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Abstract

We can think of a **DDX**® audio amplifier as a high power Digital-to-Analog (**D/A**) converter. Most engineers intuitively understand that measurements made on a **D/A** converter may need to be performed differently from those made on linear amplifiers due to their digital vs. analog input signal. This paper will help you to understand and validate the methods used to measure the performance of **DDX**® amplifiers.

Introduction

We need to address three specific requirements for testing **DDX**® amplifiers:

- A digital generator for driving the amplifier
- A band-limiting filter on the input of the test equipment
- A true-differential input to the measuring equipment is needed due to bridged output stage

DDX® Requires Digital Input Signals For Testing

DDX® amplifiers process PCM information. In order to test them, a high quality digital generator is required that is capable of synthesizing all the necessary signals required for the various tests. At Apogee Technology, Inc., we use the **Audio Precision System Two** because it provides the correct digital generator needed for testing and also has two balanced differential measurement channels with approved low-pass filters for proper digital audio testing.

Some have used a high quality sine wave generator together with an analog to digital (**A/D**) converter as a digital signal source. This approach is not recommended for the following reasons:

- There is a possibility of clipping the signal, thus introducing distortion in the digital wave shape.
- There is no accurate reading of peak analog input level vs. the dB FS output of the **A/D** converter.
- You don't know if you're measuring the characteristics of the amplifier or those of the **A/D** converter.

If a proper digital signal source is not available as part of the measurement equipment, an alternative is to use a digital test CD to produce the test signals. One can play them from the S/PDIF output of most current CD players. An excellent CD for this purpose is the "Denon Audio Technical CD" (# C39-7147-EX). Another choice is the "Sheffield/Coustic Set-Up and Test Disc".

Test Equipment Must Have A Balanced Differential Input

Many class D amplifier designs use full bridge outputs. In a full bridge amplifier, both ½ bridge outputs are typically positive with respect to ground but they produce anti-phase signals (180º apart). The average voltage level is at ½ of the unipolar supply rail. The speaker is placed between them in a floating manner with no reference to ground being necessary and the difference between them is what drives the speaker.

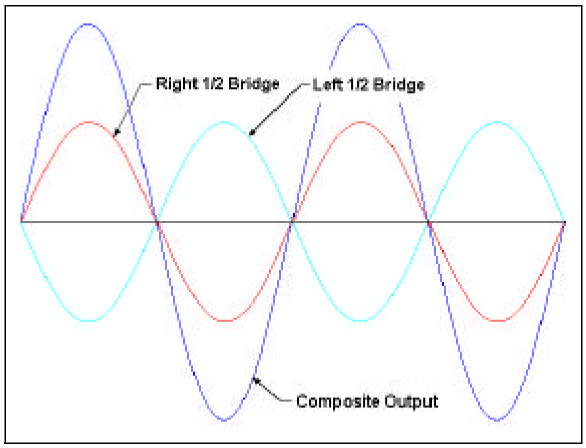

Figure 1. Class D Amplifier Outputs (Binary)

<u>NOTE:</u> Never ground either side of any full-bridge power output stage, e.g., through an oscilloscope.

Switching amplifiers incorporate a passive L-C low-pass filter on each side of the bridge to reconstruct the analog signal. One side of the bridge is in-phase with the signal and the other side out of phase, as shown in **Figure 1**. The peak-to-peak AC voltage across the speaker reaches approximately twice the power supply voltage. If the measurement equipment does not have balanced differential inputs (i.e., if gain and phase response of one input does not exactly match the other) the measurement will indicate small gain and/or phase errors but distortion measurements will not be significantly affected. This is because the difference of two out of phase sine waves is a new sine wave with a phase shift.

DAMPED TERNARY (**DDX**®) amplifiers also incorporate low pass filters on each side of the full bridge to reconstruct the analog signal. Again, one side is in-phase with the signal and the other side out of phase; but each side of the full bridge output comprises ½ of the signal like a half-wave rectified waveform, as shown in Figure 2. The peak-to-peak differential AC voltage across the speaker again reaches approximately twice the power supply voltage.

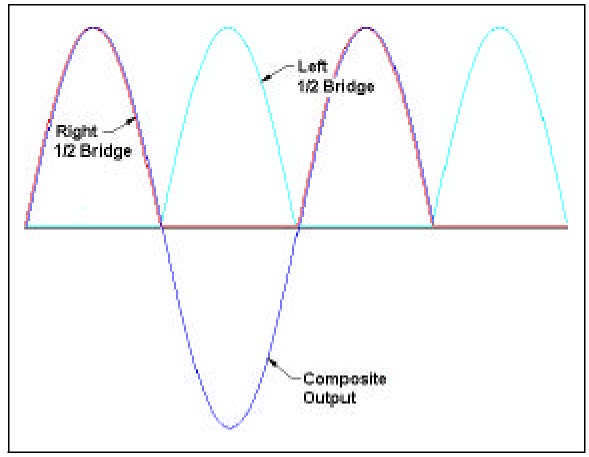

Figure 2. DDX® Amplifier Outputs (Ternary)

Using a poor quality differential input to the test equipment or simply "floating" the input from a single-ended measuring device may produce inaccurate results. As Figure 3 shows, a difference in gain between the "+" and "-" inputs will be measured as distortion due to the asymmetric waveforms on the two sides of the bridge.

In addition, a phase mismatch between the inputs of the test equipment will produce a waveform with a crossover distortion as shown (exaggerated) in Figure 3. Using test equipment with a balanced differential input with high common mode rejection ratio (CMRR) and inherent phase matching will produce measurements without false distortion products. Testing performed at Apogee indicates that the measurement equipment should have a CMRR greater than 65 db over the full 20 Hz to 20 kHz bandwidth in order to measure the output correctly.

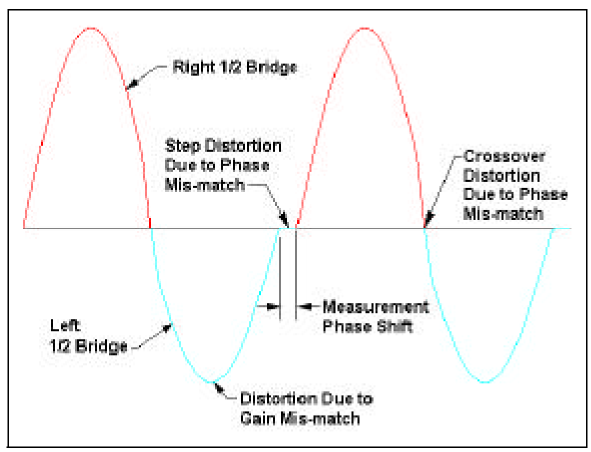

Figure 3. Distortion introduced by mis-matched differential inputs.

What Is Heard vs. What Is Measured

Digital audio inherently contains quantization noise from the sampling process. In order to minimize the total noise in the audio bandwidth, techniques such as oversampling and noise shaping are used in the DDX process. This spreads the noise over a wider spectrum and displaces most of it to higher frequencies. (It's like squeezing all of your toothpaste to one end of the tube.) The noise power is not reduced but it is 'squeezed' into a higher part of the frequency band beyond the range of human hearing. The result is a new, wider range frequency with considerably reduced noise within the 'flattened' part, the audio band itself. The overall effect is that above the audio bandwidth, the noise floor rises as shown in Figure 4. Since humans can only hear what falls within the audio band, the result is a very quiet audible noise replicating the original source.

What About Using Older Analog Test Equipment

A problem arises when we use older, wide response test equipment to measure distortion and noise. This test equipment is usually analog in nature and may have a measurement bandwidth of 200 kHz or more. The test equipment will combine the larger out-of-band noise with the smaller audible noise, resulting in a reading that is not representative of audio performance within the 20 kHz bandwidth. It will read the wide noise spectrum and report it as if it were all audible noise when doing a total harmonic distortion plus noise (THD+N) or signal-to-noise (SNR) measurement. In addition, the common mode noise from the PWM carrier signals can cause distortion in the input circuits of older test equipment. For example, THD+N measurements performed at Apogee with a popular piece of test equipment having a "floatable" single-ended input and a built-in "30 kHz low-pass filter" were in error by less than 20% when measuring full power output but reported more than 10 times the actual value when measuring low power output levels.

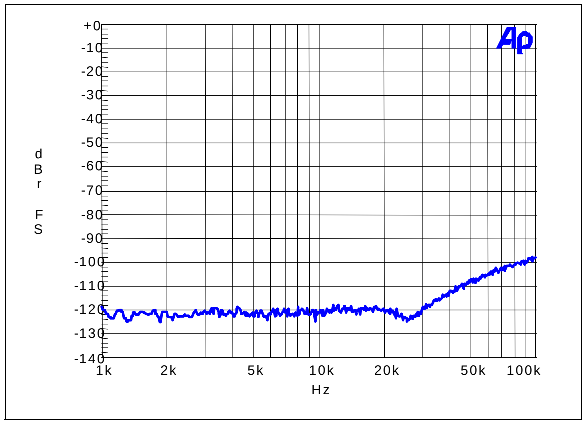

Figure 4. Noise Floor After Noise-Shaping

How To Correctly Measure Noise In Digital Amplifiers

The solution is to insert a low-pass measurement filter in series with the output of the amplifier to remove all components above 20 kHz so that we can measure just what is being heard. A 20 kHz "brick wall" filter will ensure that inaudible noise components above 20 kHz will be insignificant with respect to the overall measurements.

NOTE: The L-C filter on the amplifier's output does not provide enough attenuation to the out-of band noise to accurately represent in-band noise. Its main purpose is to attenuate the carrier and the carrier sidebands caused by the switching frequency.

The AES17-1998 Specification - Measurement of Digital Audio Equipment

For the reasons we have been discussing, the **Audio Engineering Society (AES)** published the **AES17-1998** specification for testing digital audio components. All manufacturers today base their testing methods for digital audio components on this or similar specifications. The intent is to measure noise that the consumer hears (in-band) vs inaudible noise (out-of-band). In order to test for noise levels in Digital Audio amplifiers, an "**AES17"** filter is introduced in line with the measurement equipment. This "brick wall" filter provides a sharp cut-off at 20 kHz that will fully pass the audio spectrum and reduce the out of band components (>24 kHz) by more than 60 dB. It must be inserted between the balanced differential input and the measurement circuitry within the test equipment.

The official AES17-1998 filter specification says:

"4.2.1.1 For the upper band-edge frequency of 20 kHz, the standard low-pass filter shall have the following characteristics:
a) passband response deviation: ***£ ± 0.1 dB, 10 Hz £ f £ 20 kHz****;*
b) stop-band attenuation: ***> 60 dB, f > 24 kHz****."*

This is to make sure that readings contain only relevant distortion components and noise that are within the audible region.

Tests That Are Affected By Out-of Band Noise Levels

The tests presented below require the use of a balanced differential input and an **AES17** (or equivalent) filter at all times on the input to the test equipment. These are the most commonly specified tests but the AES17-1998 specification includes others as well.

%THD (Total Harmonic Distortion)

%THD is computed by measuring each term in the following expression:

$$\%THD = 100 \times \frac{\sqrt{S_2^{\ 2} + S_3^{\ 2} + \ldots + S_n^{\ 2}}}{\sqrt{S_1^{\ 2} + S_2^{\ 2} + S_3^{\ 2} + \ldots + S_n^{\ 2}}} \qquad \textit{Eq. 1}$$

where the S_1 term is the power level of the fundamental frequency and the $S_2 \ldots S_n$ terms are the power levels of the harmonic frequencies. It requires identification and measurement of each fundamental and harmonic and then a mathematical combination of the terms to provide a %THD result. This test eliminates noise and other non-harmonically related signals from the measurement.

%THD+N (Total Harmonic Distortion Plus Noise)

The %**THD+N** is defined by the following formula:

$$\%THD + N = 100 \times \frac{\sqrt{S_2^{\ 2} + S_3^{\ 2} + \ldots + S_n^{\ 2} + N^2}}{\sqrt{S_1^{\ 2} + S_2^{\ 2} + S_3^{\ 2} + \ldots + S_n^{\ 2} + N^2}} \qquad \textit{Eq. 2}$$

where the S_1 term is the power level of the fundamental frequency, the $S_2 \ldots S_n$ terms are the power levels of the harmonic frequencies, and the N term is the power level of the RMS value of non-harmonically related signals from all sources combined. The N (noise) term contains signal components such as the noise floor, and the effects of the power supply ripple, etc. One measures the entire output spectrum while using a notch filter that removes the fundamental frequency and then factors the fundamental back into the denominator expression. This measurement is specified on most data sheets.

%THD+N vs. Frequency

Measurements of **%THD+N** are taken at each octave frequency from 20 Hz to 20 kHz and a smoothed curve is generated. Data sheets typically show at least two plots of this measurement, one at full power output and another at 1 Watt output.

%THD+N vs. Amplitude

%THD+N is measured with a fixed frequency, e.g., 997 Hz sine wave at levels from 0 dB FS (full output power) to the minimum level of interest, e.g., -30 dB FS in steps no larger than 3 dB and a smoothed curve is generated.

Dynamic Range (Signal To Noise Ratio Or Noise In The Presence Of Signal)

A 997-Hz sine wave at –60 dB FS is input and the R.M.S. output signal is measured using a notch filter that removes the fundamental frequency. This measurement is referenced to the full output at 0 dB FS.

SNR (Signal to Noise Ratio Or Noise In The Absence Of Signal)

When a DDX® amplifier is commanded with a digital zero input there is no output, not even noise! In order to measure the operating noise floor in the zeroed output one should drive any alternate channel at a low level, e.g., –60 dB FS in order to defeat the muting circuitry. This will result in a measurable reading in the channel being measured.

Conclusions

Using single-ended test equipment to measure the differential outputs of full bridge amplifiers may result in erroneous measurements. Incorrectly including out-of-band components in the measurement of a digital amplifier will not accurately represent audio bandwidth performance. The use of a true differential measurement input along with an **AES17** filter will ensure valid measurement results. Test methods for digital audio equipment, as per **AES17-1998,** are suggested to measure **DDX®** amplifiers.

Appendix A: A 30 kHz Low-Pass Filter For Differential Audio Measurements

NOTE: Figure B-1 shows a true differential input, single-ended output, 4-pole, 30 kHz low-pass filter. This filter will allow one to get measurements on digital audio amplifiers that will be close to the actual values, but it does not fully conform to the **AES17-1998** specifications.

When constructing this filter you must match the ratio of R1 to R2, R3 to R4, R5 to R6, R7 to R9, R8 to R10, R11 to R12 and R13 to R15 within 0.01% of each other.

All capacitors should be NPO types. Again you must match the ratio of C3 to C4 and C5 to C9 within 0.1% of each other.

The circuit shown is limited to a ±10 volt input. Scaling of the input circuitry may be needed when used with higher bridge voltages. R1 and R2 may each be replaced by a voltage dividing resistor pair, each having a parallel resistance of 4.99K, with .01% matching.

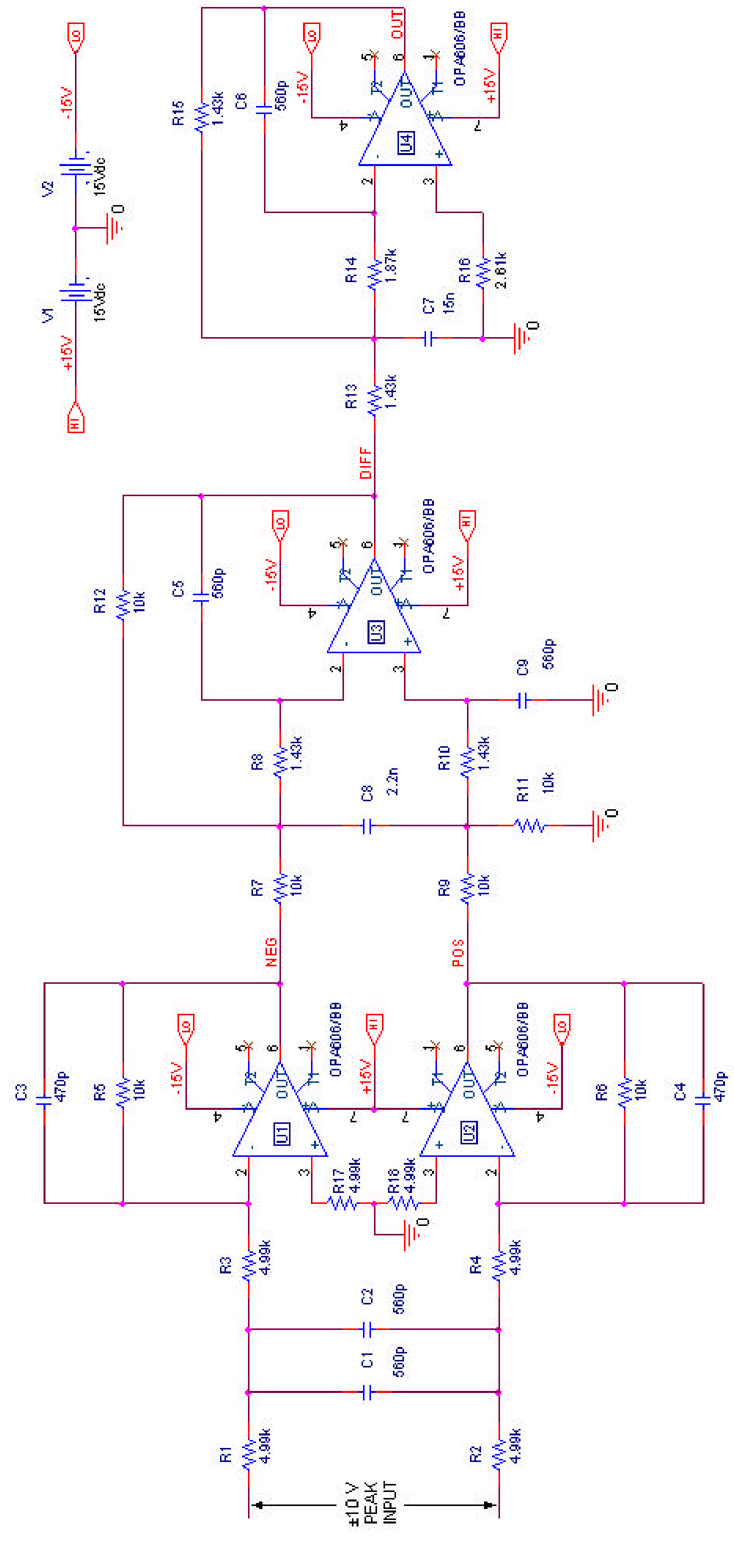

Figure B-1. A True Differential Low-Pass Filter With Single-Ended Output For Measuring Bridged Output Digital Amplifiers.