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Testing Power Amplifiers

Audio Precision

Application Note // By Adam Liberman

APPLICATION NOTE

Introduction

Audio Precision APx series audio analyzers and APx500 measurement software are well suited to testing power amplifiers. This paper covers the fundamental measurements for testing power amplifiers, with specifics on how to best accomplish the tests using APx hardware and software.

Power amplifiers present a unique set of testing challenges that are usually not encountered when working with digital or low-level analog circuits, due to the fact that they must supply significant current as well as voltage to their loads. Factors such as power supply current and voltage limitations, thermal characteristics of the output devices and associated heatsinks, and the resistive and reactive components of the load must be considered during testing to produce meaningful results. Whether we are talking about high-powered amplifiers for venues, headphone amplifiers, or integrated chips powering miniature speakers in hand-held devices, many of the same considerations and test procedures described in this paper may be applied.

Measurement Equipment

A wide variety of APx500 audio analyzers, controlled by APx500 software, may be used for audio power amplifier measurements. Audio Precision's APx500 Flex software may also be used with third-party audio interfaces that support ASIO. However, because audio interfaces don't have input ranging, they can't handle the voltage levels of moderate sized power amplifiers, nor can they measure very low levels without introducing noise.

Dummy loads are required for almost all amplifier tests. Normally, they must be non-inductive, and should be of sufficient size and properly heatsinked to endure the full output power of the amplifier under test.

The Dale NH series with 1% or better tolerance is a popular choice when heatsinked wirewound

resistors are needed.

For small amplifiers, precision thin-film metal film resistors with a low temperature coefficient may be used. A practical configuration is to purchase 8 Ω

resistors and to parallel an additional 8 Ω resistor on each channel for 4 Ω measurements. This makes impedance switching easy while also doubling the power handling into 4 Ω . For testing headphone amplifiers, load impedances such as 8 Ω , 16 Ω , 32 Ω , 100 Ω , and 600 Ω may be appropriate, depending on the intended load range.

Filterless class-D amplifiers are a special case, as their design relies on the inductance of the connected speaker to form a low-pass filter. Testing them with a purely resistive load may affect the results of the maximum power output and other tests and not reflect field performance. The value of the necessary load inductance for testing will need to be determined from the specific test requirements.

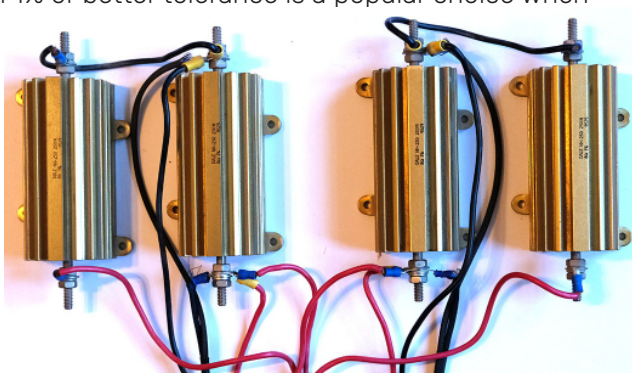


FIGURE 1.
250 W dummy loads with
8/4 Ω switching.

When bench testing class-D amplifiers, an Audio Precision AUX-0025, 0040, or 0100 switching amplifier measurement filter should be inserted in series with the analyzer input to filter out switching amplifier carrier components that might overload the analyzer input and cause erroneous readings. For production testing, comparison measurements can be done to determine if external filters are needed. Low-pass filtering for the analyzer should still be configured in the software, whether or not an external passive filter is used.



FIGURE 2.
Audio Precision AUX-0025 filter.

For a detailed explanation of the output characteristics of class-D amplifiers and the use of the AUX-0025, 0040, and 0100 switching amplifier measurement filters, read the white paper [Measuring Switch-mode Power Amplifiers](#) (insert link) by Audio Precision co-founder Bruce Hofer.

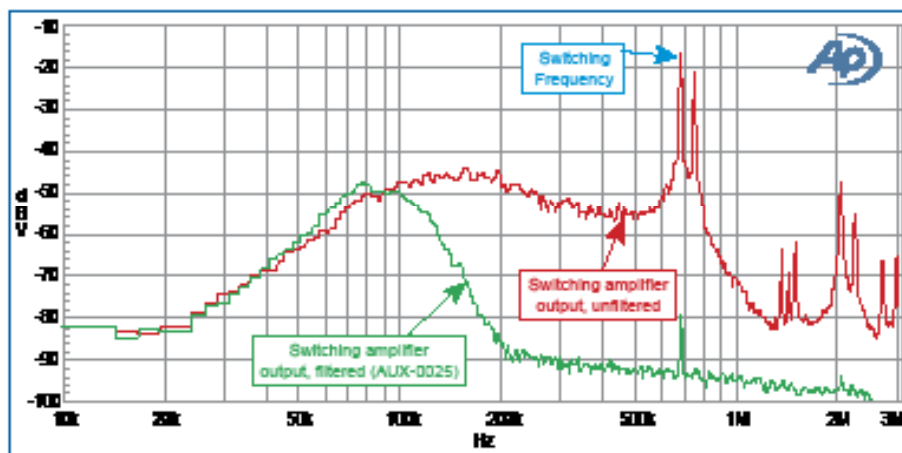


FIGURE 3.
Class-D switching noise removed by the AP AUX measurement filters.

Connections

Connect the generator outputs of the analyzer as appropriate to the amplifier inputs, utilizing any of the provided analog or digital output connector choices. Connect the analyzer inputs, as well as the dummy loads, to the output terminals of the power amplifier. Dummy loads must be connected directly to the amplifier outputs as shown Figure 4 below.

Connecting them at the analyzer could damage the internal wiring between the XLR input and the banana jacks on the analyzer. Speaker wires should be sized to minimize voltage drop.

When utilizing the Audio Precision AUX-0025, 0040, or 0100 switching amplifier measurement filters, hook them up as shown in the following diagram. The measurement filters have balanced XLR connectors for easy connection to the balanced inputs on the analyzer. Class-D outputs are usually balanced and have a DC bias on them, so they must be connected to the balanced inputs on the analyzer, either via the filters (preferred) or directly. Non class-D outputs can be connected to either the balanced or unbalanced analyzer inputs, but the configuration that introduces the lowest hum and noise should be chosen.

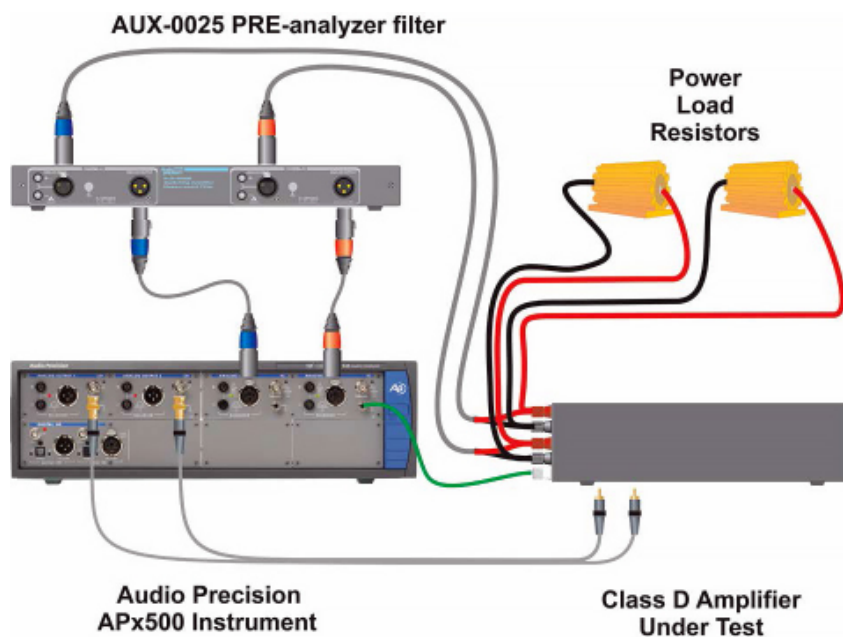


FIGURE 4.
*Analyzer comparison for
amplifier test.*

Pay close attention to the grounding configuration to minimize external noise and hum pickup. A heavy ground wire should be connected from the analyzer banana jacks to the amplifier and the AUX filter (if used). For balanced connections, sometimes lifting the shield on one end of the audio cables reduces ground noise. For the most accurate test results, verify the configuration with the lowest noise using the RMS Level result and the FFT Spectrum Monitor in Signal Path Setup.

Make sure that you have minimal voltage drop in the power lines when testing high powered amplifiers with unregulated power supplies. The line voltage should be checked at the workbench, first without powering the amplifier, and then powering it to full output. Any difference is the voltage drop, and this will reduce the voltage on the amplifier's unregulated power supply rails for the output stages and reduce the maximum output power. If voltage drop is significant, reduce the use of power strips and extensions, avoid having other significant loads on the circuit, and use a circuit with adequate wire size that is not an excessive distance from the load panel. Sometimes a rheostat is used to adjust the line voltage to a target voltage for testing.

References Levels

A number of power amplifier measurements, such as signal to noise ratio, crosstalk, and frequency response, are typically done driving the amplifier to an output level of 1 watt. To conveniently set the level of the APx500 generator, go to Signal Path Setup, open the References section, and use the Auto Gen Level function to automatically establish the dBrG reference level of 0dB to produce a 1 watt output.

For results using watts as a unit, the reference impedance must be set as appropriate (typically 8 Ω or 4 Ω , and sometimes 2 Ω) in signal path setup. The best way to avoid errors is to create a second signal path in the APx sequencer (menu item: Project -> Add Signal Path) and set the reference to 8 Ω in Signal Path1 and 4 Ω in Signal Path2. Then, delete the set of basic measurements that appear in Signal Path2, and include copies of those measurements from Signal Path1 that need to be rerun at 4 Ω .

Additional Setup

Bandwidth and/or low-pass filters are typically set for 20 kHz. Use of the sharp cut-off AES17 20 kHz filter is especially important for testing class-D amplifiers. Coupling may be set for AC or DC – usually this will be of little consequence except for phase measurements below about 500 Hz and frequency response below 20 Hz. If you choose DC coupling, make sure to check for excessive DC across the amplifier outputs. This may be checked using the APx500 DC level measurement, with or without signal present.

Tests and Measurements

In the following sections, we will review common amplifier tests and how to best perform them with APx500 software. To avoid confusion, we will use the term “test” to refer to the parameter being measured, “measurement” to refer to the selected APx500 sequencer measurement, and “result” to refer to the particular graphic result panel selected from the filmstrip display in the bottom portion of the screen. Many tests can also be performed using APx500’s bench mode.

Power Output

Output power is one of the most fundamental power amplifier tests, and the APx500 software provides multiple measurements to facilitate measuring it. Perhaps more than any other test, the results are highly sensitive to the conditions under which they are made and the methodology used. Factors that influence the test include the frequency range, the distortion level chosen to determine maximum power, the number of channels driven simultaneously, the warm-up procedure, the duration of the test tone, the ambient temperature, the type of test signal, and the load.

In order to promote fair comparisons for consumers, The United States Federal Trade Commission “Amplifier Rule” defines some of the test parameters that are required when power ratings are advertised for home entertainment products in the US. First written in 1974, a rulemaking proposal is pending to add further refinements.

¹ The pending rule specifies the following updated test conditions: “Any power level from 250 mW to the rated power shall be obtainable at all frequencies within the rated power band of 20 Hz to 20 kHz without exceeding 1.0% of total harmonic distortion plus noise (THD+N) at an impedance of 8 ohms after input signals at said frequencies have been continuously applied at full rated power for not less than five (5) minutes at the amplifier’s auxiliary input.” It further clarifies, in summary, that both channels of a stereo amplifier must be driven, or at least the left and right front channels of a multichannel amplifier. The full text contains additional stipulations, such as preconditioning and ambient temperature.

Regardless of whether or not you are testing for FTC compliance, the rule serves as a good starting point for specifying and controlling the parameters that affect the testing. For high-quality devices, power output is often specified at a level slightly under clipping where distortion is minimized, to avoid the misunderstanding by consumers that an amplifier specified at, say 1%, has this level of distortion at normal volumes with program material.

If the amplifier has a compressor or peak limiter that prevents its output from reaching the clipping point, the maximum output may alternatively be specified as the point where the signal is compressed by 1 dB. This can easily be observed in the linearity result of the Stepped Frequency Sweep measurement. The following APx500 measurements are useful for doing power tests:

Stepped Level Sweep

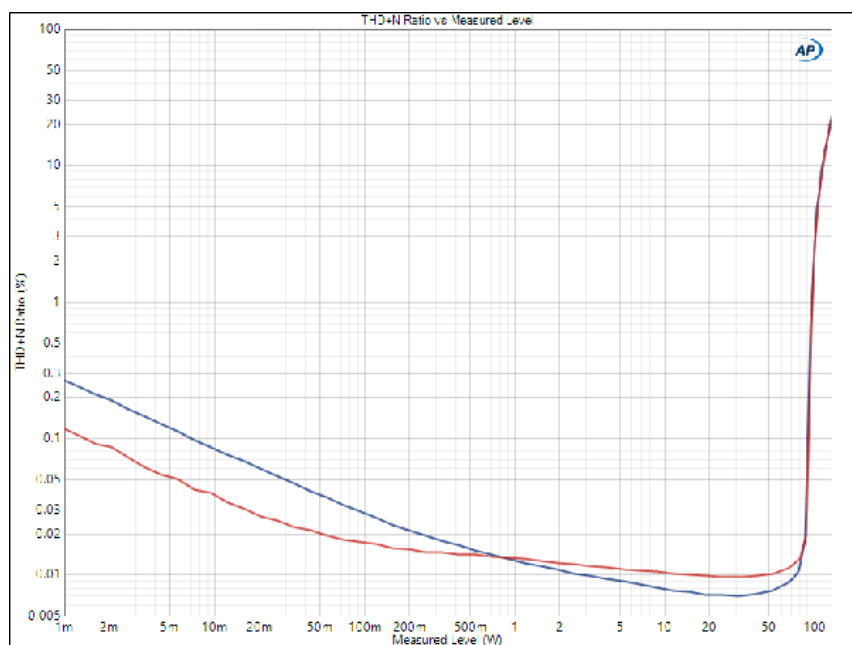


FIGURE 5.
THD+N power curve

This measurement can produce a classic THD+N vs power curve, as seen below. It provides a view of distortion and noise across a wide range of power levels, and shows the characteristics of the inflection point where the amplifier starts to clip.

In addition, it also produces results showing only THD (without noise), distortion at a specific harmonic, or distortion over a group of harmonics (such as all even or all odd). A generator frequency of 1 kHz is typical, but additional measurements can be made at other frequencies. Observation of the distortion level near clipping is helpful in determining a practical distortion setting for the Maximum Output Level measurement described below. While larger sweep steps will suffice for most of the curve, a series of closely spaced steps will be necessary to show the detail at the inflection point. This can be accomplished by selecting “custom” for the sweep type and defining the individual sweep points, or by doing a separate closely-spaced sweep for the area near clipping and appending or splicing it to the remainder of the curve.

Maximum Output Level

APx500 provides two fixed-frequency and one sweep measurement to find the maximum output level of an amplifier. The fixed frequency measurements are described here. The Regulated Sweep measurement is described in the section on measuring power bandwidth. In many cases, such as during design or production test, a single-point measurement will suffice after it has already been established that the output level is not frequency dependent. The single-point measurement can also of course be repeated at selected spot frequencies in lieu of running a complete Regulated Sweep measurement.

The Maximum Output Level measurement finds the maximum output power by iterating the generator level until a target distortion level is achieved. If the measurement fails to find the maximum level, it may be necessary to adjust the start level and/or the number of initial steps.

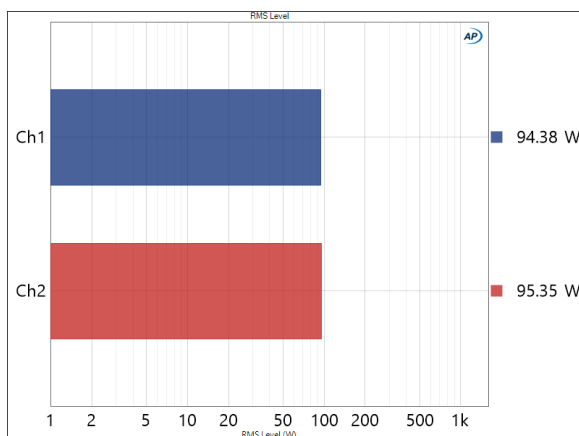


FIGURE 6.
Maximum power output.

Maximum Output

Level CEA-2006 uses a modified test signal. ANSI/CEA-2006 is an ANSI specification written by the Consumer Technology Association (formerly Consumer Electronics Association) for the testing of power amplifiers mobile (car) audio systems. CEA-490 is likewise a specification for testing AC mains powered amplifiers.

Both use a similar test signal comprised of an 1 kHz sine wave burst, with 20 cycles at full level, followed by 480 cycles at -20 dB. CEA-2006 also includes a 50 Hz signal for testing subwoofers, with 10 cycles at full level, followed by 20 cycles at -20 dB. Both are designed to reduce the heat buildup and power demands of a continuous signal, and can be useful for testing amplifiers that cannot tolerate a continuous test signal for long enough to otherwise get useful readings.

The Maximum Output Level CEA-2006 measurement can also be used to test the dynamic headroom of amplifiers that have no problem with a continuous test signal. Dynamic headroom is meant to show the extra output that an amplifier can provide for the short transients in typical musical program material.

To derive it, the results of both the Maximum Output Level and Maximum Output Level CEA-2006 measurements are compared, and the difference between them is expressed in dB.

At the same time that maximum output level is being measured, the maximum input level (often referred to as "sensitivity") can be obtained from the Generator Level result of the Maximum Output Level or Maximum Output Level CEA-2006 measurements, or the THD+N Ratio or THD+N Level (vs generator) results of the Stepped Level Sweep measurement. Practical speakers present a complex impedance load to an amplifier, and a full investigation of amplifier performance should include testing with reactive as well as pure resistive loads. This can be accomplished by manually attaching components in series or parallel with the dummy loads. By adding Aux Control or Program steps in the APx500 sequencer, you can automatically control external test-beds that can change the amplifier load to produce appended measurements with different load conditions.

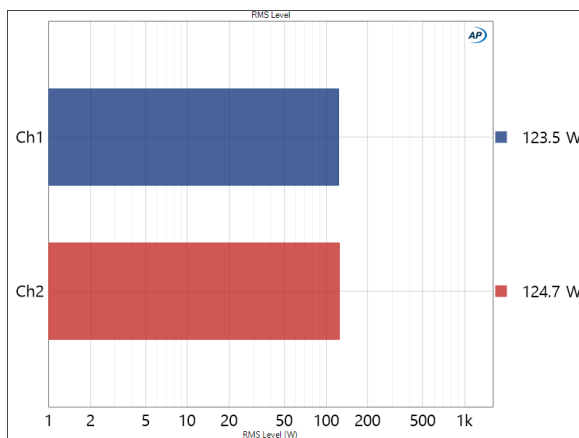


FIGURE 7.
Maximum power output
using CEA-2006 test
signal.

Measurement Recorder

Measurement Recorder makes multiple measurements over a defined period of time, and can be a very powerful tool for observing the behavior of amplifiers where heat buildup is an issue. A common technique is to apply a signal at just below clipping and observe the THD and/or THD+N results over time. In some amplifiers, the THD and THD+N will be seen to steadily rise. These amplifiers will tend to give inconsistent distortion measurements unless preheat and cool-down times are carefully controlled.

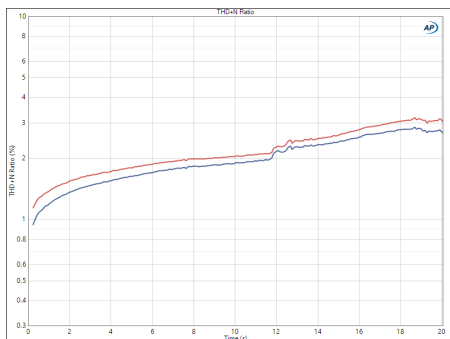


FIGURE 8.
10: THD+N rise over time.

Frequency Response

The APx500 software provides three different methods for capturing frequency response, utilizing the Continuous Sweep, Stepped Frequency Response, and Multitone Analyzer measurements. Two additional measurements, Frequency Response and Acoustic Response, are variations of Continuous Sweep. Continuous Sweep is the most useful for amplifier measurements, being much faster than a traditional stepped frequency sweep.

Continuous Sweep offers a choice between two test signals: Log Chirp and Fast Sweep. Log Chirp is the fastest, but produces only THD and not THD+N results, which may be a factor if you wish to capture THD+N and frequency response simultaneously. Both test signals produce simultaneous crosstalk results. Testing is typically performed with a power output of 1 watt, but can also be performed at different levels to observe any changes (see Power Bandwidth below).

Frequency response is usually stated as a range of frequencies, typically within a variation of ± 3 dB. A couple of convenient features of the software facilitate stating the results. One is the relative level result.

This result automatically normalizes the response curve to a chosen reference frequency (typically 1 kHz). If you add upper and lower limits for the desired level deviation, then you will be shown the exact frequencies that cross those

points. The other feature is the deviation result. Here, you can choose fixed frequencies, and you will be shown the amount of deviation at each of them. This is most useful when you have better performance and are more likely to reach the bandwidth limits of the test before a predetermined amount of attenuation occurs.

Some class-D amplifier designs have LC output filters that interact with the load impedance, causing significant variations in the response curve. In these cases, it is especially important to run the frequency response test multiple times with different loads. It should be remembered, however, that the impedance of actual speakers can deviate greatly from their nominal impedance, depending on the frequency. Therefore, the frequency response of these amplifiers in practical usage may not correlate well with the test results.

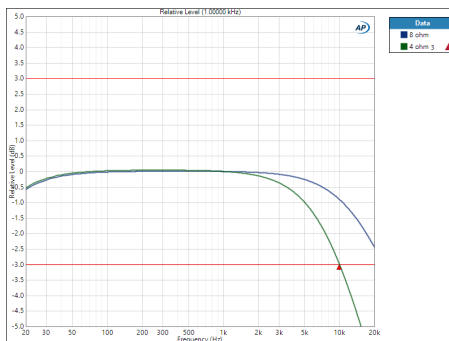


FIGURE 9.
Frequency response of a particular class-D amp at 8 Ω and 4 Ω .

Power Bandwidth

Power bandwidth is the range of frequencies within which an amplifier can produce full output power. The full power measurement is made by establishing the maximum output at 1 kHz (see Maximum Output above) and then running a frequency response sweep at that level (Continuous Sweep measurement with Fast Sweep signal, or Stepped Frequency Sweep). If the THD+N does not stay at or below the specified percentage at all frequencies in the specified test range (typically 20 Hz to 20 kHz), then the generator level is lowered slightly and the test is run again to see if it passes at the new “maximum output power.”

If the frequency response deviates by more than 3 dB, or the amplifier meets THD+N requirements only over a narrower bandwidth, then some testing procedures may allow the frequency range to be redefined. If testing is being done to meet the revised FTC rule, however, the bandwidth must be fixed at 20 Hz to 20 kHz, except in the case of sub woofers.

Another way to test the power bandwidth is to use the Regulated Frequency Sweep measurement. It is essentially a combination of Maximum Output Level with a Stepped Frequency Sweep, where the generator level is increased at each step until THD+N exceeds a preset amount. The analyzer bandwidth will need to be widened to include the distortion products of the higher frequencies – otherwise, the regulation will never settle because THD+N will remain too low. Note that because the results are independent of frequency response (except where the roll-off or maximum input level of the device makes it impossible to achieve full output), this measurement will not produce numbers that can be used in a typical power bandwidth specification. For amplifiers that have limited heat dissipation and cannot tolerate the sustained signal of this measurement, you can alternatively make multiple passes at different frequencies using the Maximum Output Level CEA-2006 measurements.

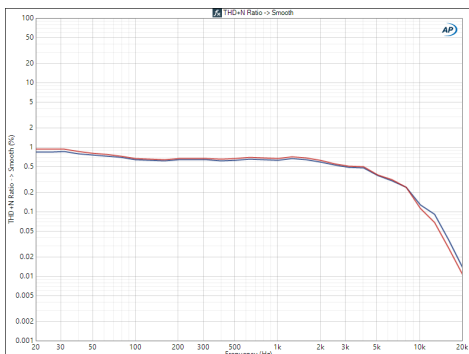


FIGURE 10.
*Power bandwidth using
Continuous Sweep.*

Noise

The Signal to Noise Ratio measurement provides a quick way to test signal to noise without extra calculations. Set the generator to an output level of 0 dBG (already established earlier with Auto Gen Level to produce 1 watt at the output of the amplifier), and start the measurement. Sometimes signal to noise ratio will be specified with respect to full power output, but a measurement at a consistent level of 1 watt makes a comparison with standards and other amplifiers more valid. Signal to noise ratio is sometimes also referred to as dynamic range or hum and noise on specification sheets. The absolute output noise level may be measured using the Level and Gain measurement. The amplifier inputs should remain connected to the analyzer outputs with the generator turned off, so that they are

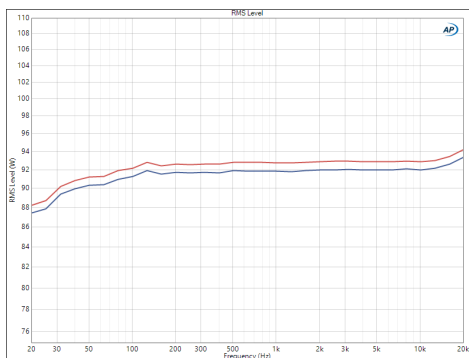


FIGURE 11.
*Power bandwidth using
Regulated Frequency
Sweep.*

backterminated with the correct impedance. Equivalent input noise (EIN) may be calculated by subtracting the gain from the result. Both signal to noise ratio and absolute noise level are typically measured utilizing a bandwidth of 20 Hz to 20 kHz, utilizing a sharp low-pass filter at 20 kHz. Careful attention must be given to a number of factors in order to obtain accurate results, including the quality and orientation of the cables, the presence of ground loops, and nearby external hum and noise sources. To aid in identifying and eliminating these issues, the noise spectrum maybe visualized using the Signal Analyzer measurement in Sequence Mode, or the FFT measurement in Bench Mode.

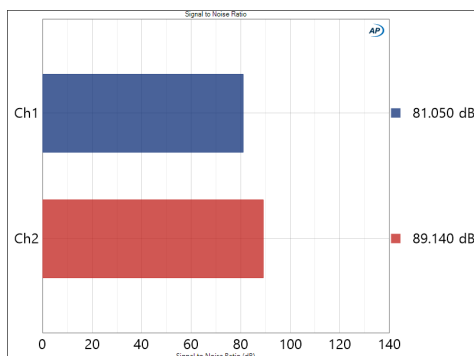


FIGURE 12.
Signal to noise ratio.

Harmonic Distortion

The classic THD+N vs level graph for amplifiers may be produced by running the Stepped Level Sweep measurement (described in more detail in the Power Output section (link) above). This gives insight into what the lowest achievable level is and the behavior of the amplifier as it approaches clipping (by observing the shape of the inflection point). Results are available both in ratio and level units. The ratio result is what's typically seen on specification sheets. The level result can also be insightful, as the shape of the curve will show the point where harmonic distortion starts to dominate over the noise component.

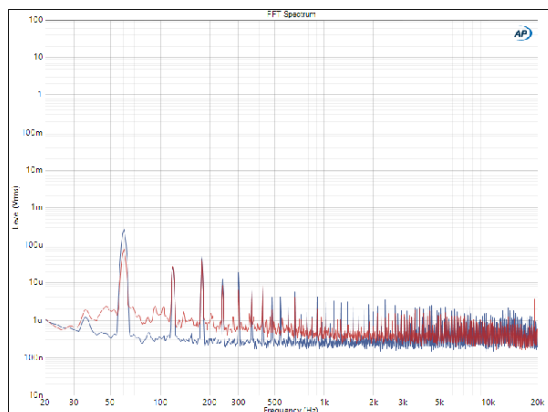


FIGURE 13.
Noise spectrum showing a significant hum component.

For single-point tests at a fixed frequency and level, there's a measurement simply called THD+N. To observe harmonic distortion at a fixed level across the audible bandwidth of 20 Hz to 20 kHz, the Continuous Sweep or Stepped Frequency Sweep measurements may be used. Continuous Sweep

also allows you to enable nested levels, creating an appended graph at multiple generator levels settings.

Bandwidth is also normally set to 20 Hz to 20 kHz, so therefore measurements of fundamentals over 10 kHz will include only noise and have no harmonic distortion products. Measuring harmonic distortion together with noise became a standard primarily because it wasn't practical in early audio test equipment to build filter circuits to separate them apart.

However, with modern audio measurement software like APx500, it is easy to exclude noise from the distortion analysis. The Stepped Level Sweep, Stepped Frequency Sweep, Continuous Sweep, and THD+N measurements all produce a set of harmonic distortion results that not only include THD+N, but also THD as well as individual harmonics and groups of harmonics.

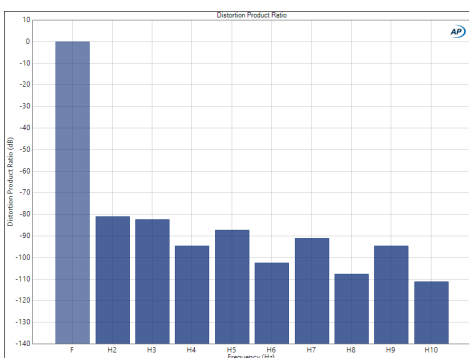


FIGURE 14.
*Distortion Product Ratio
result of the THD+N mea-
surement.*

As described previously for visualizing noise, the distribution of distortion products across the frequency spectrum may also be observed with the Signal Analyzer measurement in Sequence Mode, or the FFT measurement in Bench Mode.

Intermodulation Distortion

Intermodulation distortion measurements utilize two simultaneous signals to create intermodulation products. The intent is to measure performance characteristics that may not be revealed by using a single-tone stimulus, and to observe distortion at higher frequencies, since all distortion products are inband. Slew-rate limiting, for example, will cause an increase in IM distortion, but may not be revealed in THD+N tests. DIM/TIM (dynamic intermodulation or transient intermodulation) distortion testing is specifically intended for power amplifiers. APx500 provides both the DIM Level Sweep and DIM measurements.

Different waveform types may be chosen to conform to different DIM test standards. Unique to all of them is that the signal is comprised of a square wave and a sine wave. Because DIM testing requires the use of a high quality analog square wave generator, it is only available when using the APx555 analyzer or the APx525 analyzer with the AG52 option. For the more

common intermodulation distortion tests, APx500 provides for swept and fixed testing utilizing the IMD Level Sweep, IMD Frequency Sweep, and IMD measurements. Each of these may be configured to measure SMPTE, DFD, CCIF, and MOD IMD, at both standards-defined and user-defined frequency combinations.

TD+N is a result unique to the Multitone measurement. It is a sum of everything between the multitone fundamentals, which includes both harmonic and intermodulation products, as well as noise. It does not correlate to any measurement standard, but can be useful as it shows distortion behavior under the stress of more than one or two tones. Distortion will manifest as a difference between the TD+N Ratio and Signal to Noise Ratio results.

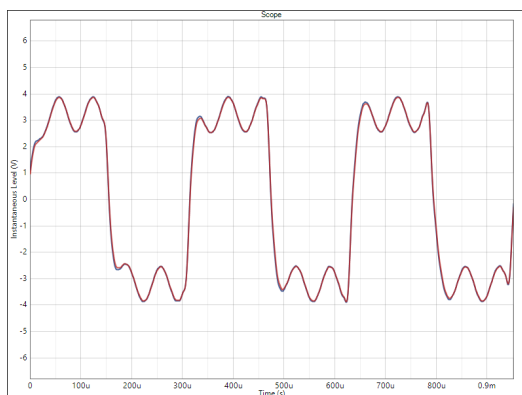


FIGURE 15.
Scope monitor view of the DIM test tone.

Gain

Gain is a common specification for power amplifiers. It is available as a result in numerous APx500 measurements, including Level and Gain, Continuous Sweep, Stepped Level Sweep, Stepped Frequency Sweep, and others. It is expressed as a ratio between the input and output voltages.

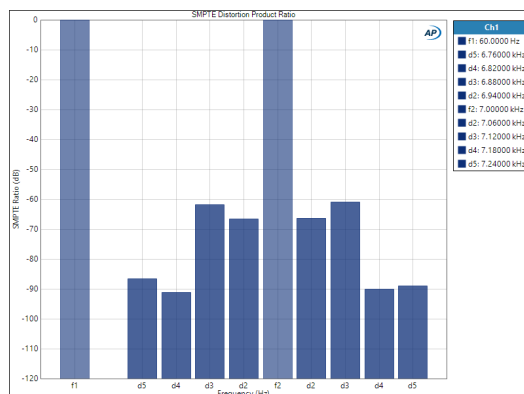


FIGURE 16.
SMPTE Distortion Product Ratio result.

DampingFactor

Damping Factor is the ratio of speaker load impedance to amplifier output impedance. It is derived from measuring level, and therefore any APx500 measurement that returns a level or level sweep may be used. Although a single-point measurement at a specific frequency can be taken, it is more informative to measure it across the entire bandwidth of the amplifier. To capture the data, a level sweep in Vrms is made with no load connected to the amplifier, and then a second sweep is made with an 8 Ω resistive load attached. AP offers the APx Damping Factor Measurement Utility ([download link](#)) to automatically calculate the ratio.

Phase

Phase can best be seen on the Phase result of the Continuous Sweep measurement. For accurate highfrequency phase results, low-pass filters should be removed and the analyzer bandwidth should be set to 20 kHz or greater. If the Audio Precision AUX-0025, 0040, or 0100 switching amplifier measurement filters are being used, they can either be temporarily removed if possible, or the results can be corrected for their presence. For accurate low-frequency results, coupling should be set to DC. Check for excessive DC across the amplifier outputs using a multimeter or the DC Level measurement.

Crosstalk

Crosstalk can be observed in the Crosstalk, One Channel Driven and Crosstalk, One Channel Undriven results of the Continuous Sweep measurement and in the Crosstalk result of the Multitone measurement (when using a special multitone with crosstalk tones), as well as in the results from the set of six dedicated crosstalk measurements. Twisted-pair speaker cables, with separation between those of each channel, should be utilized to avoid measurement errors.

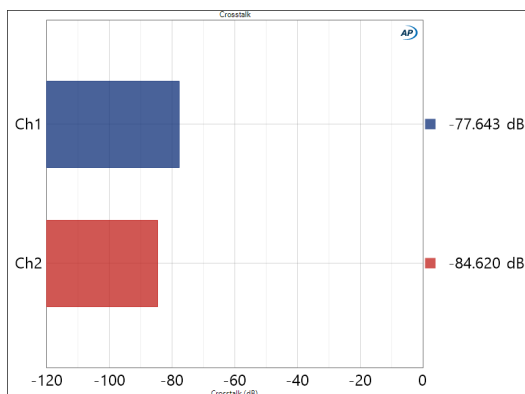


FIGURE 17.
Automated crosstalk measurement.

CMRR

Common mode rejection ratio should be tested on amplifiers with balanced inputs. It can be measured using the CMRR and CMRR IEC measurements and APx500 analyzers that have the necessary hardware built in (APx515B, APx516B, APx525B, and APx555B). For the APx585B, CMRR can be tested by constructing external cabling and utilizing the Level and Gain measurement.

Conclusion

This application note has covered many of the typical audio tests normally done on power amplifiers in design, review, and production test. Some tests, such as power supply rejection ratio (PSRR), turn on/off pop, and efficiency that are primarily design-related, have not been included but they are covered in detail elsewhere. Refer to the resources below for related articles, and reach out to AP's tech support if you have any questions.

References:

1. FTC Issues Supplemental Proposed Amendments to its Amplifier Rule to Make Testing Methods More Useful to Consumers (Federal Trade Commission) <https://www.ftc.gov/news-events/news/press-releases/2023/07/ftc-issues-supplemental-proposedamendments-its-amplifier-rule-make-testing-methods-more-useful>

Resources:

Measuring Switch-mode Power Amplifiers, by Bruce Hofer https://www.audioprecision.com/fileadmin-ap/technical-library/Measuring_Switch-mode_Pwr_Amps.pdf

Automotive Audio Testing – Amplifiers <https://www.audioprecision.com/fileadmin-ap/technical-library/Audio-Precision-AppNote-Automotive-Audio-Amplifier-Testing.pdf>

Stereo Power Amplifier Test Session (video) <https://www.audioprecision.com/blog/stereo-power-amplifier-test-session>

Measuring Slew Rate or Rise Time (blog) <https://www.audioprecision.com/blog/measuring-slew-rate-or-rise-time>

It's Hip to be Square (blog) <https://www.audioprecision.com/blog/its-hip-to-be-square> Class-D and Linear Power Amplifier Testing (slides) https://www.audioprecision.com/fileadmin-ap/technical-library/Class_D_and_Linear_Power_Amplifier_Testing.pdf

Technote 106: Measuring PSRR (Power Supply Rejection Ratio) <https://www.audioprecision.com/fileadmin-ap/technical-library/tn-106.pdf>

APx Damping Factor Measurement Utility https://www.audioprecision.com/fileadmin-ap/technical-library/DampingFactor_7.0.4.zip

APx Active Loadbox Utility https://www.audioprecision.com/fileadmin-ap/technical-library/ActiveLoadBox_v7.0.9.zip

Guidelines for Measuring Audio Power Amplifier Performance (Texas Instruments) <https://www.ti.com/lit/pdf/sloa068>