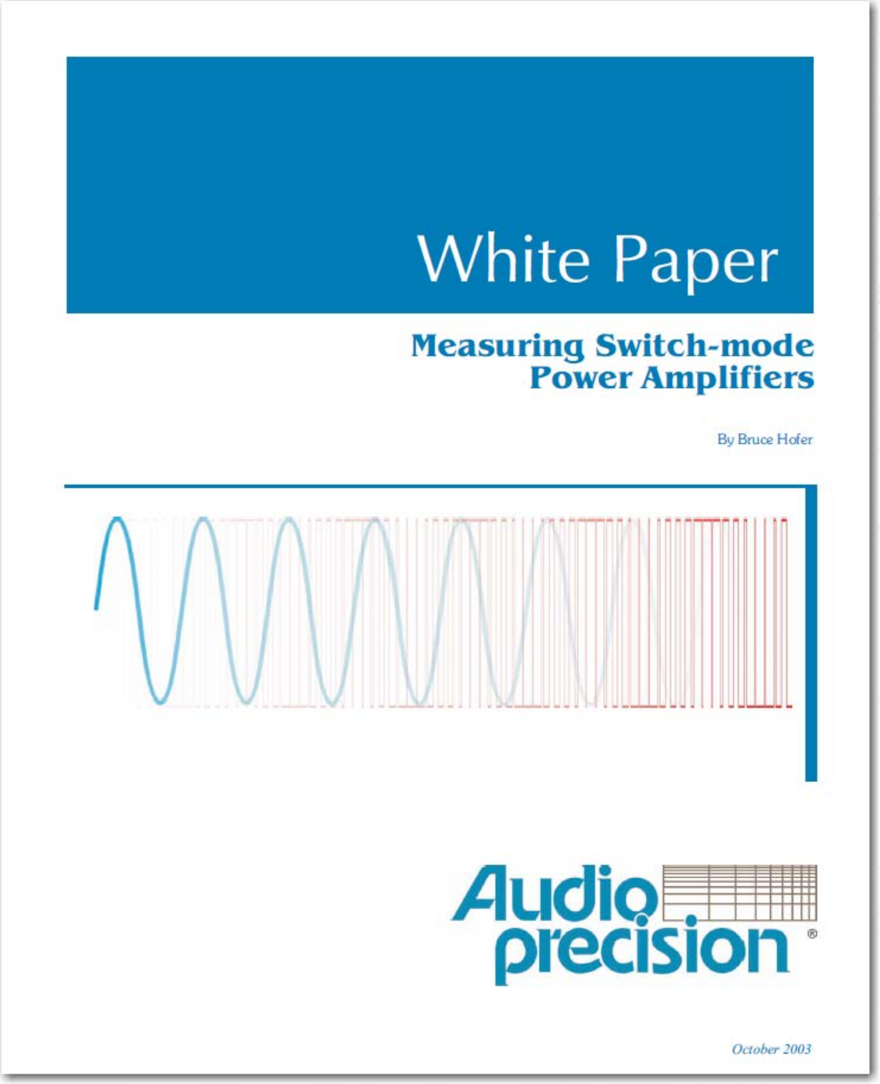
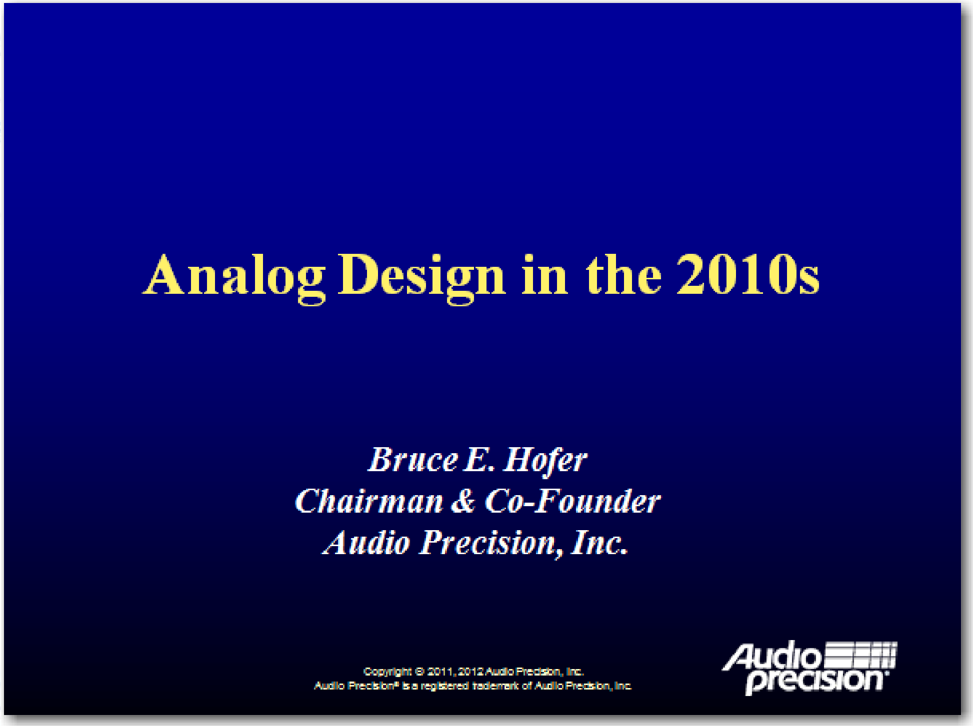
Audio power amplifier testing

- Testing linear and Class D audio power amplifiers.
- with special considerations for Class D amplifiers.

Additional Resources





Introduction

- Class D amplifiers require special filters for measurement. Once these filters are in place, testing a Class D amplifier is the same as testing a similar linear amplifier (Class A, B, or AB).
- In this presentation, we will illustrate the application of the necessary filtering, and explain why it is required.
- Then we will look at the key measurements for audio amplifier testing, whether Class D or linear.

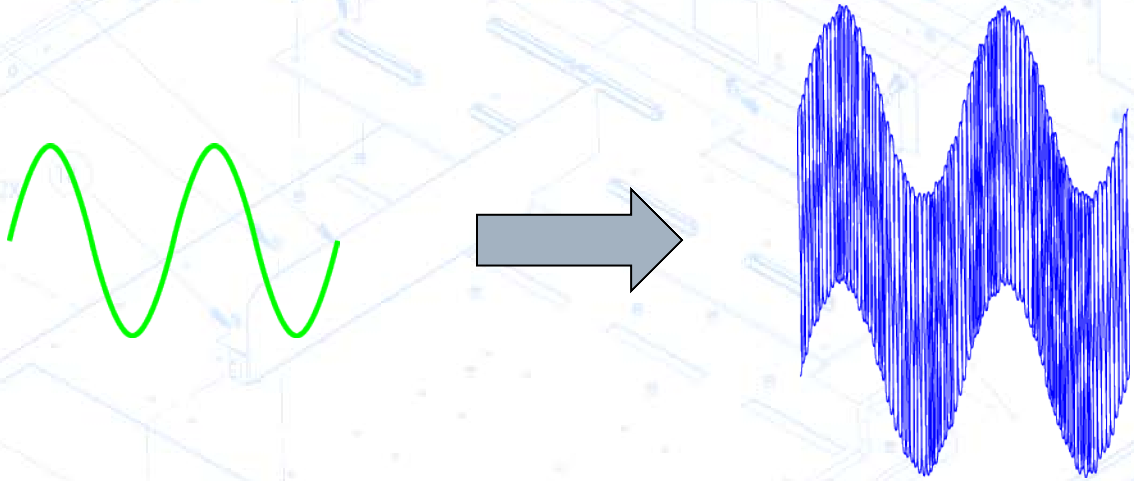
Review of Audio Terms

First, let's review a few audio terms:

- THD+N—Total Harmonic Distortion plus Noise. A classic quality metric for audio devices.
- IMD—Intermodulation Distortion
- SNR—Signal to Noise Ratio.
- LCR Filter—Inductor(L)-Capacitor(C)-Resistor(R) filter network.
- FFT—Fast Fourier Transform. A mathematical operation that transforms waveform signals from the time domain to the frequency domain, providing further insight into the nature of the signal.

Class D audio amplifiers

- In addition to the audio signal, Class D audio amplifiers typically have high-amplitude, high-frequency noise on their outputs.

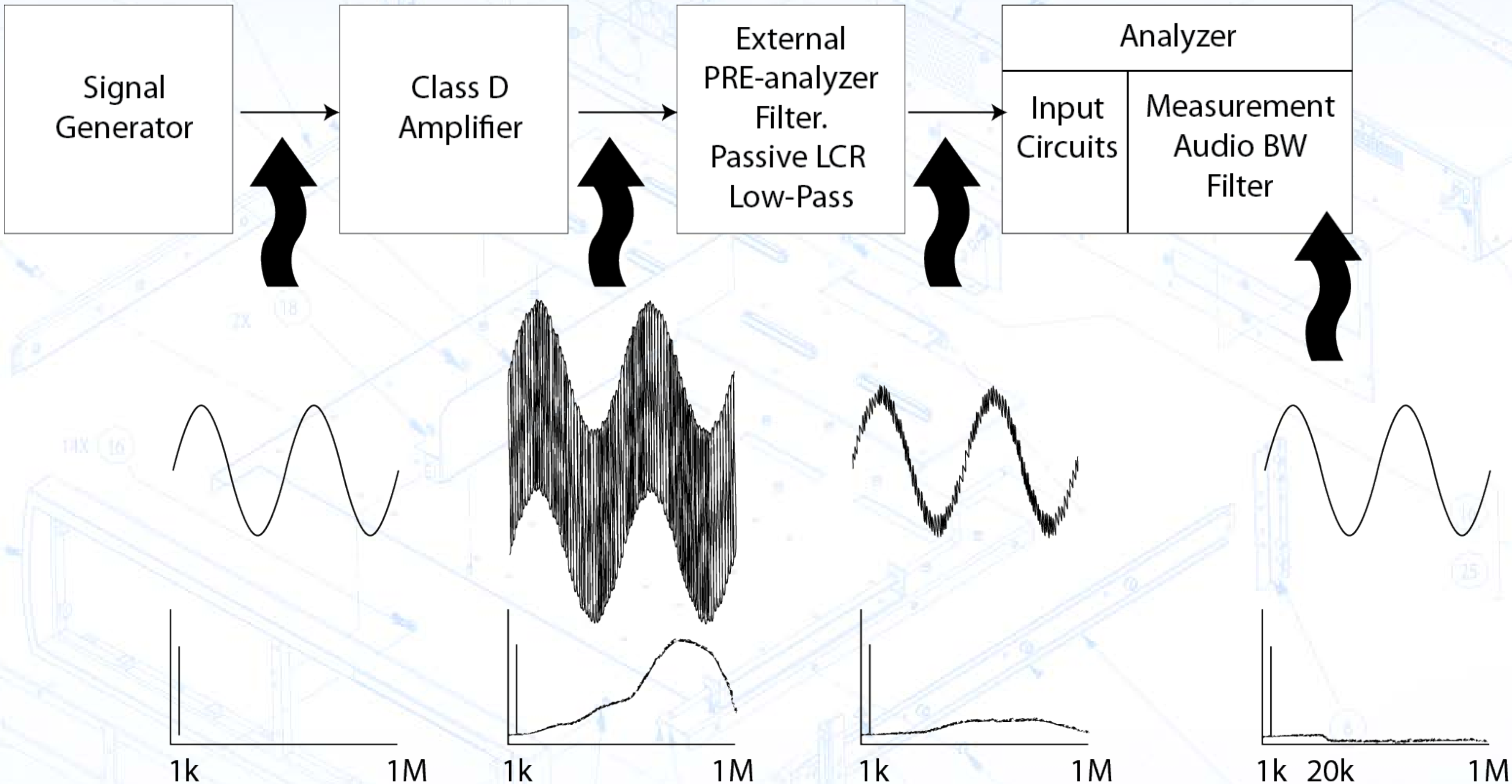


- These noise signals have very high slew rates (SR), which can cause erroneous distortion and noise readings in analyzer measurements. In some cases audio analyzer circuits can be forced into unstable states or even suffer damage.

Required filtering

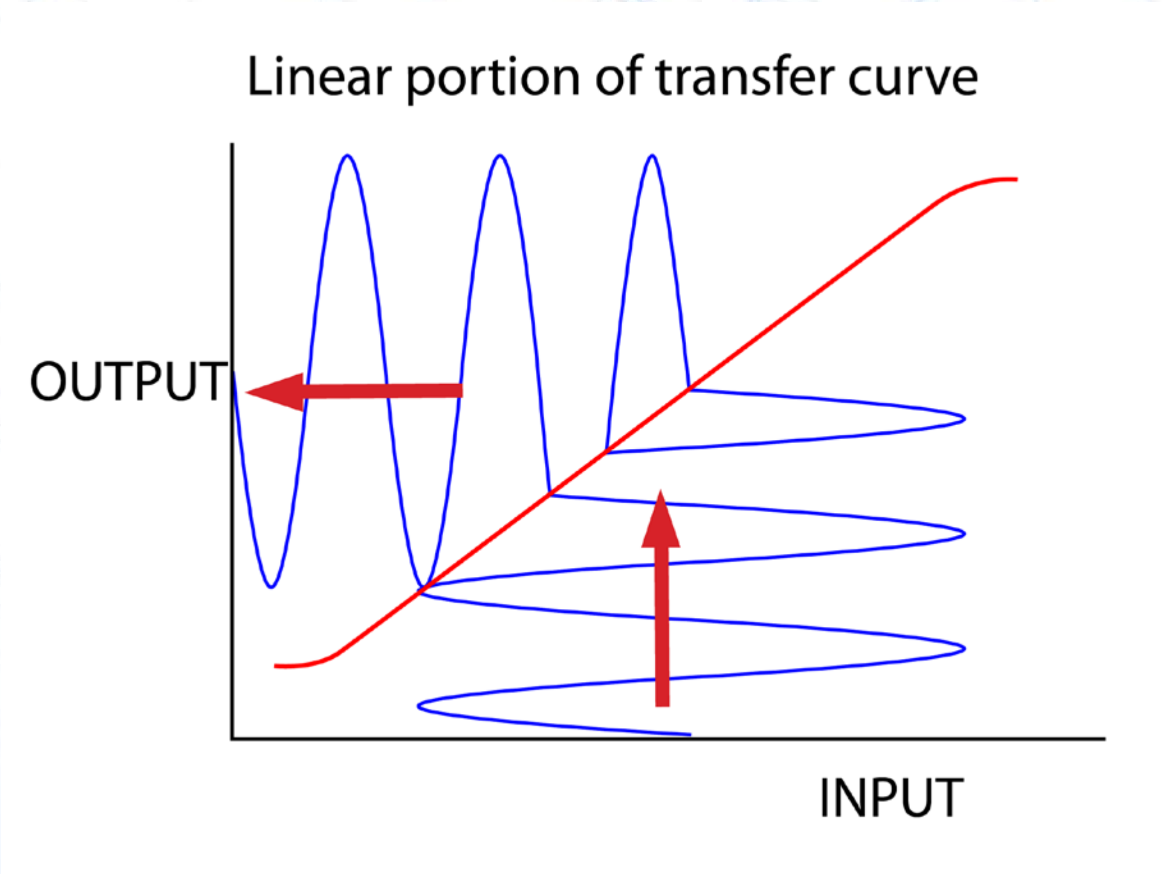
- Two kinds of filtering are necessary.
  1. **An external PRE-analyzer filter.**
     An external, passive filter connected between the amplifier outputs and the analyzer inputs is required, to eliminate high slew rate noise signals **before** they enter the analyzer. If this is not done, the analyzer input circuits can suffer slew rate limiting and produce invalid measurement results.
  2. **A bandwidth-limiting measurement filter.**
     An internal analyzer measurement filter is also required, to restrict the signal to the desired audio bandwidth for measurement.

Class D testing block diagram



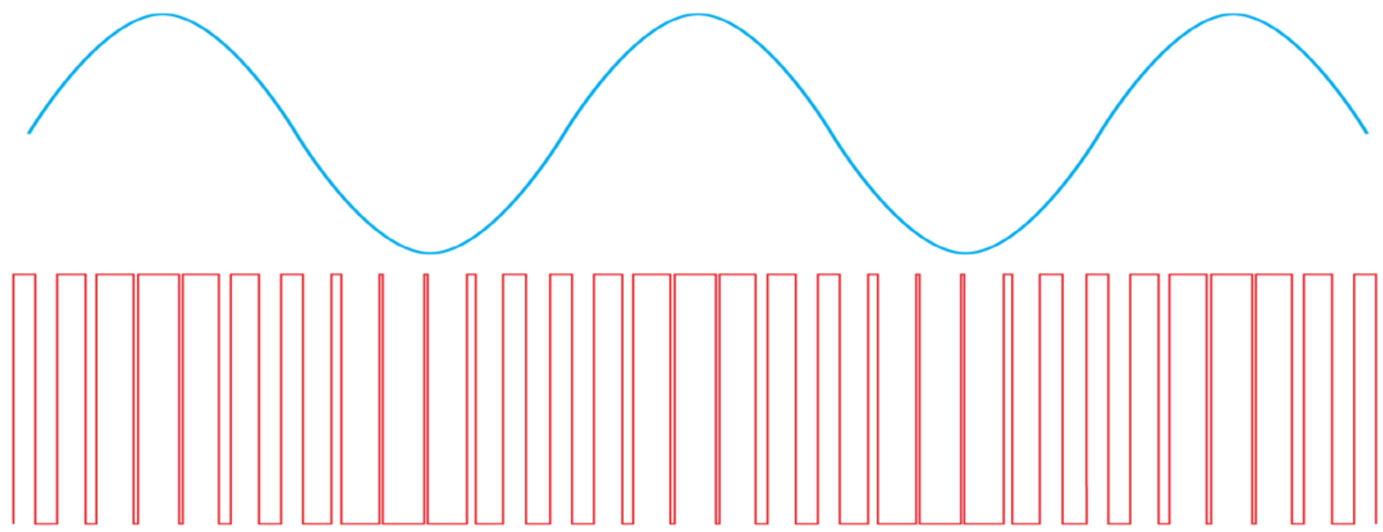
Amplifier Classes A and AB

- "Linear" audio amplifiers are Class A or Class AB. These typically have very good fidelity, but low efficiency. Active components are constantly dissipating power.



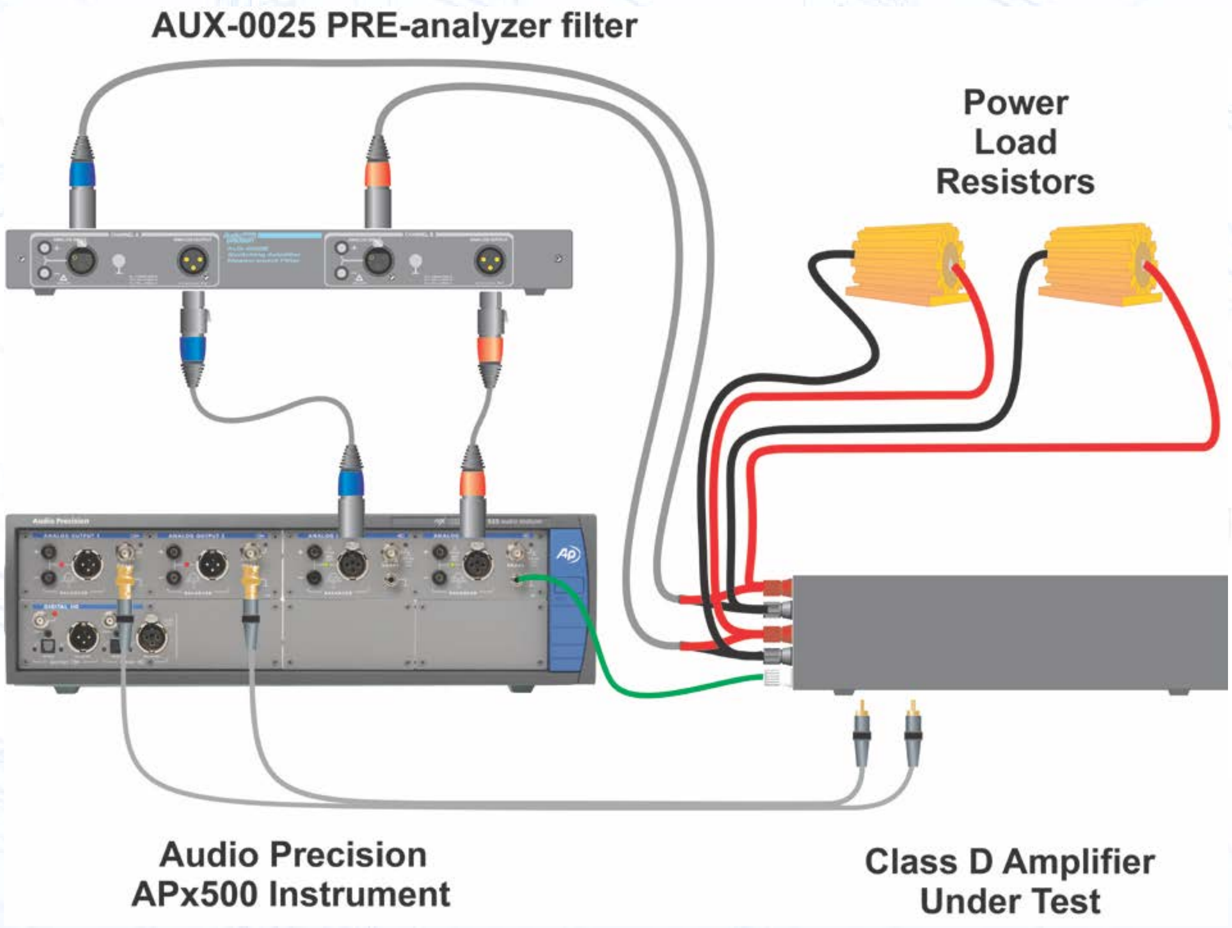
Amplifier Class D

- Class D amplifiers (switching amplifiers) can have good fidelity. Active components are “ON” or “OFF” 100% for brief pulses, dissipating very little power. These have very good efficiency, but require filtering to remove high-level high-frequency switching noise.

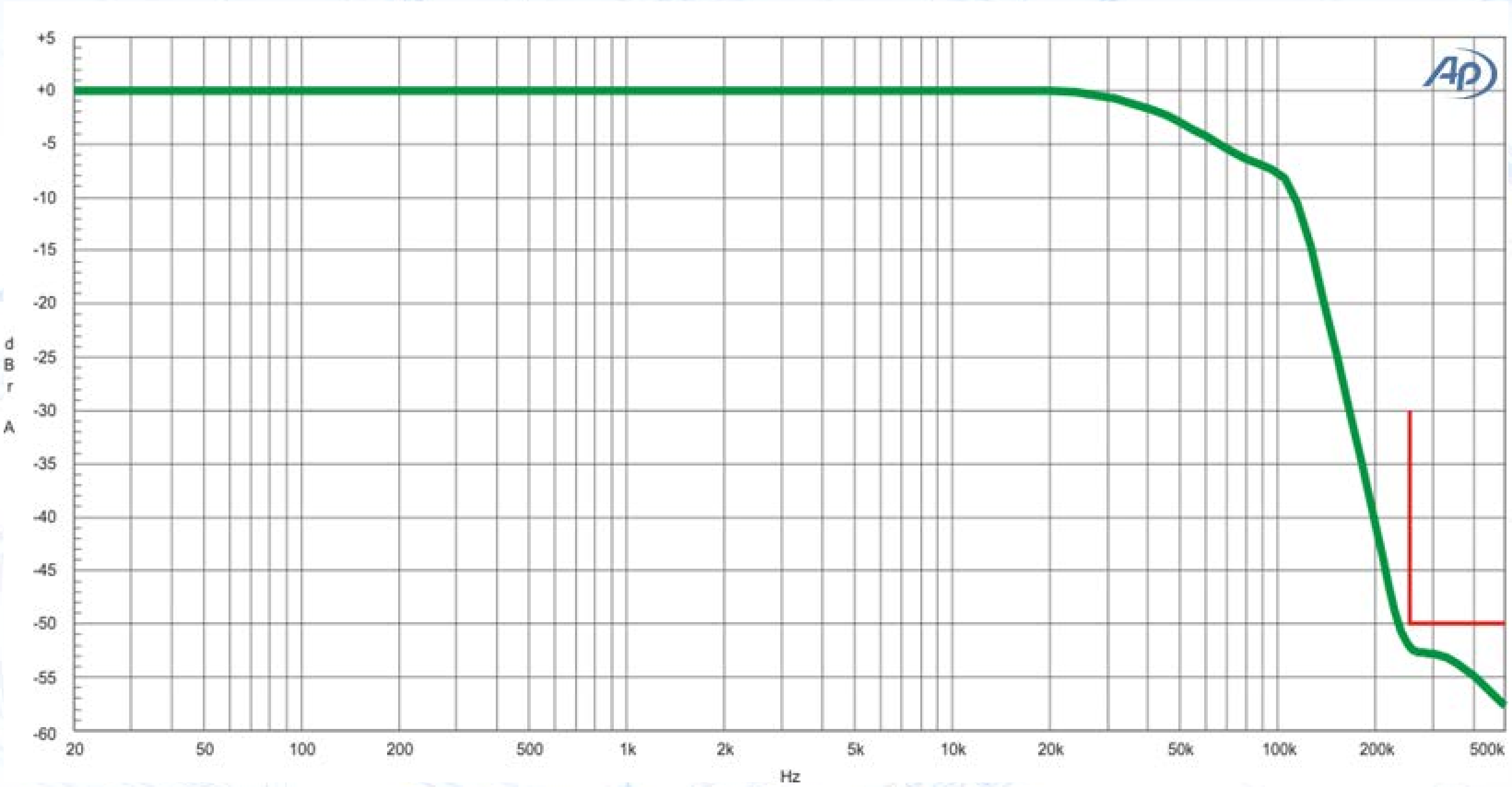


Audio Precision AUX-0025

- AUX-0025 PRE-analyzer low-pass filter

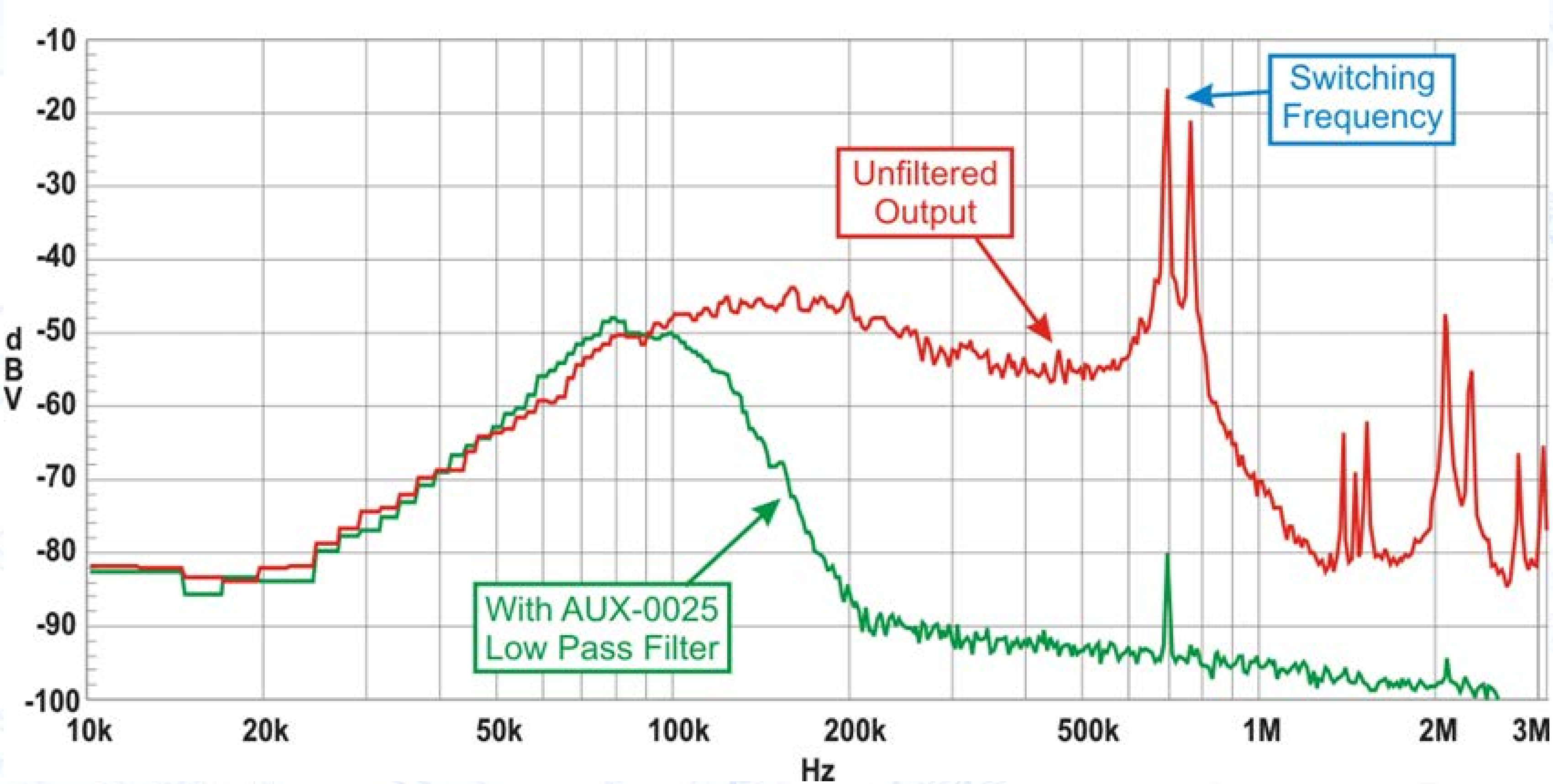


AP PRE-analyzer filter roll-off characteristic



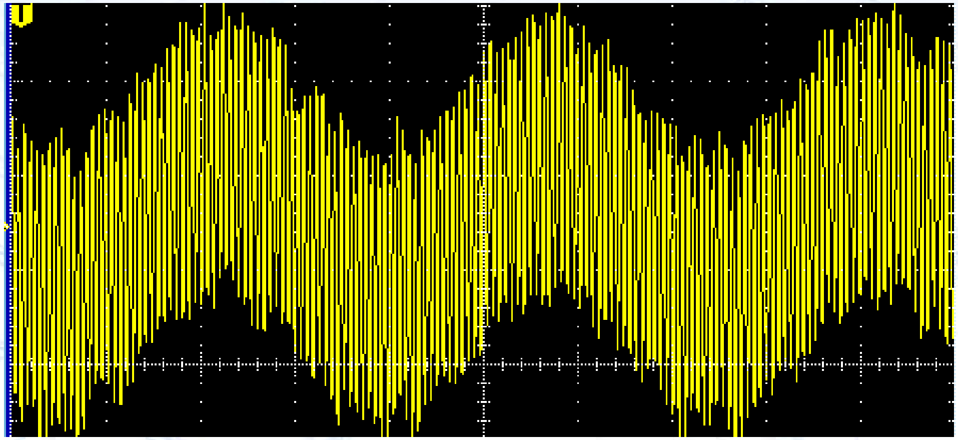
Typical of Audio Precision
AUX-0025 / AUX-0100 pre-analyzer
switching amplifier measurement filter.

PRE-analyzer filter effect in Frequency Domain

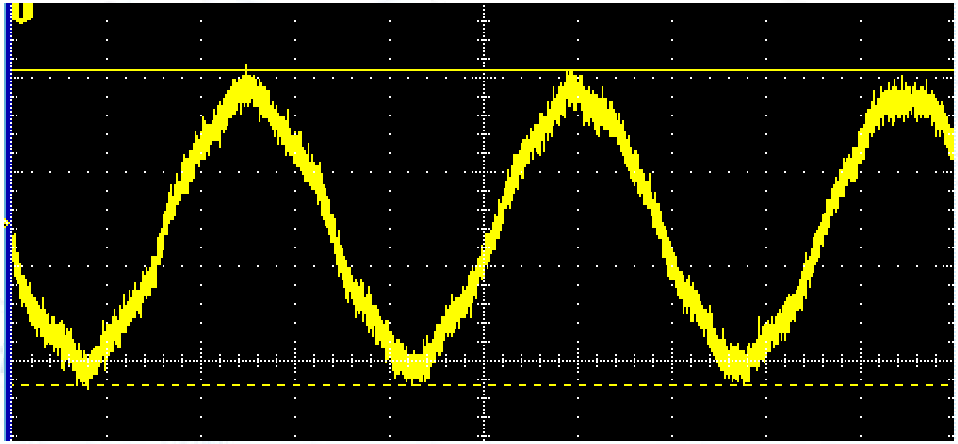


PRE-analyzer filter effect in Time Domain

- **Typical Class D Low-level Output Signal**
  Audio signal is masked by switching artifacts.



- **Output Signal after PRE-analyzer filtering**
  Audio signal is now clearly visible.



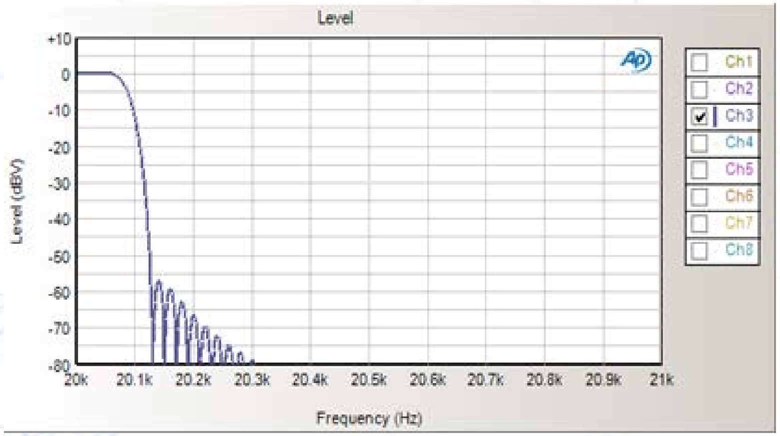
Analyzer BW-limiting measurement filter

- For Class D amplifier measurements, a second, sharp dropoff bandwidth-limiting filter is required in the analyzer.
- The AES17 standard also recommends such a filter for D/A converter measurement, and an AES17 filter is a good option as an internal filter for Class D amplifier measurements.

Analog vs. Digital Filter Implementation

Audio Precision implements the AES17 filter in hardware for 2700 Series instruments (left), and provides superior brick-wall DSP filters in the APx family of analyzers (right).

^ 20k — *Response of typical analog filter (7th pole elliptic)* — ^ 30k



Response of digitally implemented filter, typically -60 dB at <1.01 Freq

APx Series filtering

In Audio Precision APx instruments, the internal DSP band-limiting filters must be individually selected for each measurement. Some measurements (such as FFT views) do not have filters available.

As an alternative, you can reduce the analyzer’s A/D sample rate, using the input converter’s anti-alias filter to globally limit the bandwidth for all measurements.

Use both external and internal filters for Class D testing.

- Remember, an internal filter (such as an AES17 filter), whether implemented in hardware, DSP or by an A/D anti-alias filter, does nothing to protect the analyzer input stages from slew induced distortion.
- We strongly recommend that you use an external, passive LCR Pre-analyzer filter whenever testing Class D amplifiers.

Summary

- Testing Class-D amplifiers is a challenging task because of the high peak slew rate of its switching artifacts compared to the input slew rate capability of typical audio analyzers.
- A passive low-pass filter must be inserted between the amplifier output and the analyzer input to insure accurate measurements. Ignoring this recommendation can lead to extremely inaccurate measurements and potential instrument damage.

Audio Amplifier Testing

- Audio amplifier testing is quite similar for both Class D and linear power amplifiers.
- In addition to an audio analyzer, you will need:
  - Non-inductive, high power load resistors (typically 8 Ω).
  - A Variac and line voltage meter.
  - Power meter (if efficiency measurements are to be made).

Audio power amplifier testing

- ✓ Special considerations for Class D amplifiers.

Next:

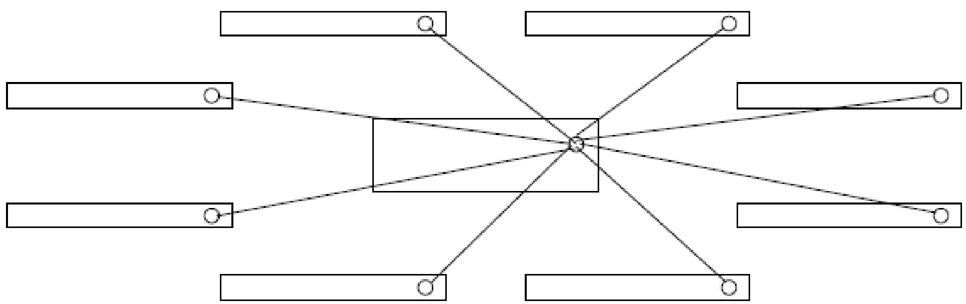
- ❑ Testing linear and Class D audio power amplifiers.

The importance of grounding

- Good grounding practice is important to achieve optimal measurement results.
- Small ground potential differences between devices in the test system (such as switchers, the DUT, and the test instrument) can couple into the signal path and cause undesirable interference or noise due to the inherent stray capacitance between signal conductors and the chassis.
- AP strongly recommends connecting the chassis ground of each device directly to the ground of the test instrument via low impedance wires.

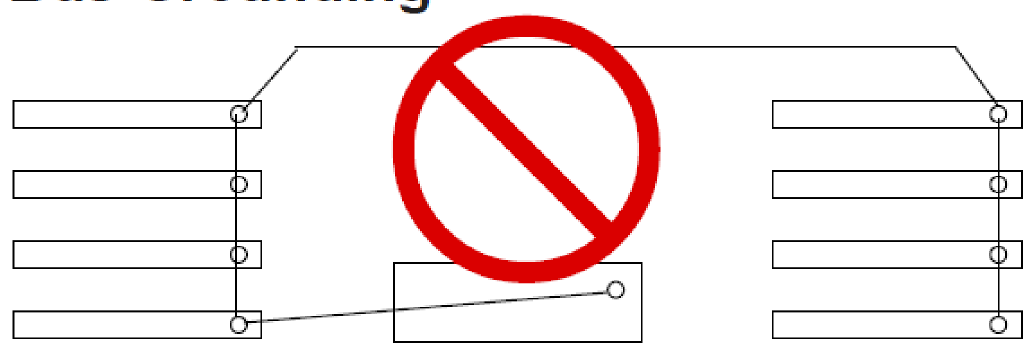
Star grounding is recommended

Star Grounding

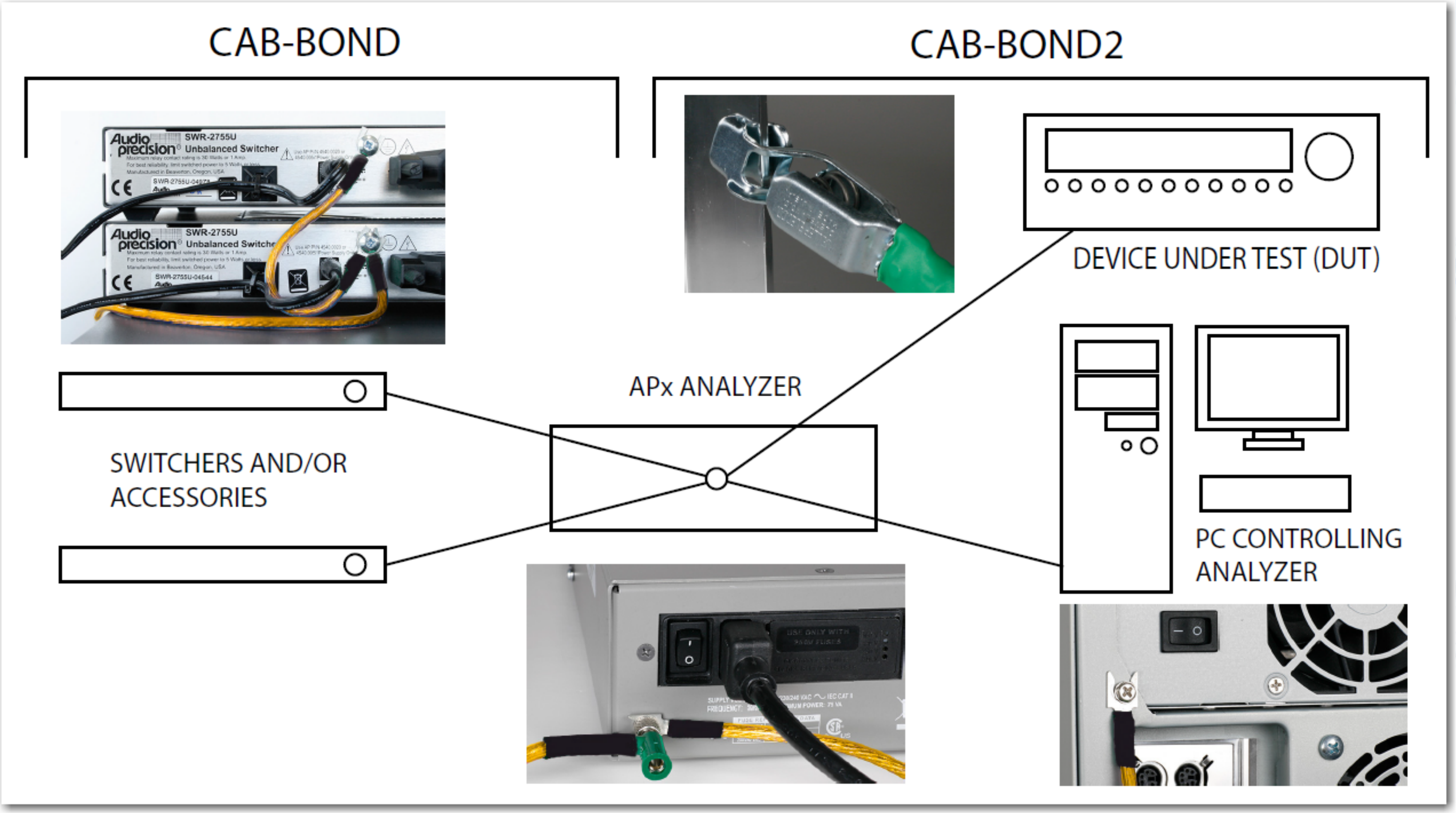


The resistance in each leg of the chain puts the devices at different ground potentials, and is not as effective as star grounding.

Bus Grounding



Grounding


CAB-BOND
CAB-BOND2
DEVICE UNDER TEST (DUT)
APx ANALYZER
SWITCHERS AND/OR ACCESSORIES
PC CONTROLLING ANALYZER
SWR-2755U
Unbalanced Switcher

Recommended measurements For R&D characterization

- Noise
- THD+N
- IMD
- Frequency response
- Interchannel Phase
- Maximum Output Power
- Crosstalk
- DC Offset
- Power Supply rejection
- Damping factor
- Efficiency

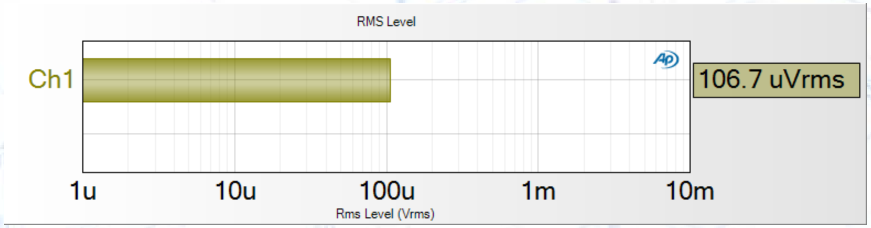
Noise (1)

- Noise is a good place to start, since noise limits the performance of many other characteristics such as THD+N, crosstalk, power supply rejection ratio and so on.
- Noise typically increases with increased bandwidth, so noise measurements should always be bandwidth-limited.
- Noise measurements are often made using a weighting filter, representing human hearing response.

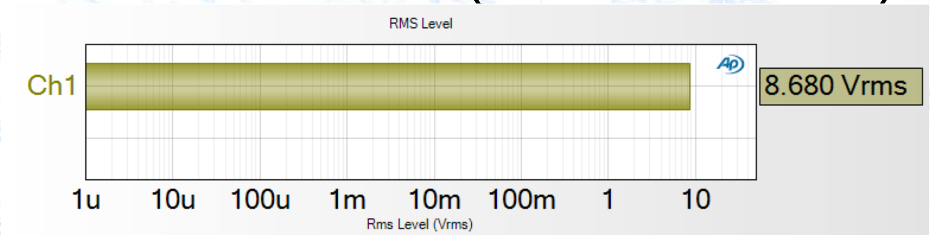
Noise (2)

- measured with a 1 MHz measurement bandwidth and no measurement filter.

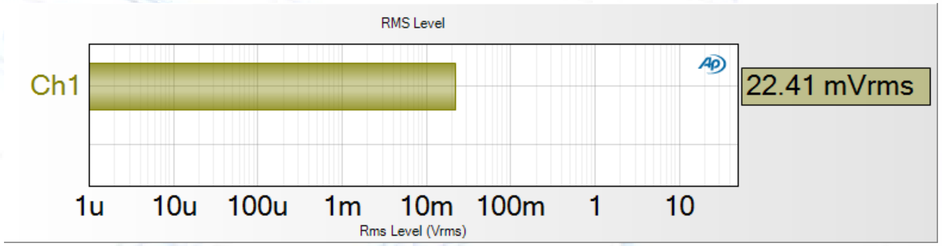
Linear



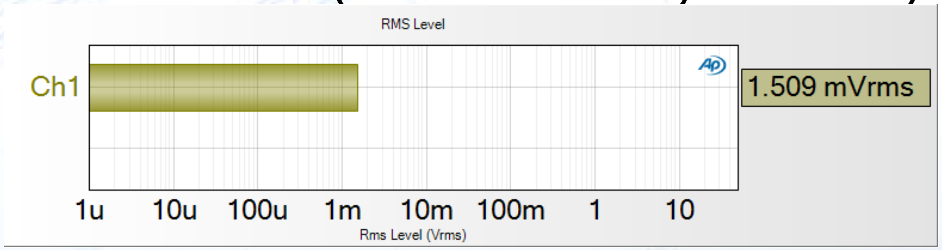
Class D (no internal filter)



Class D (add device internal filter)



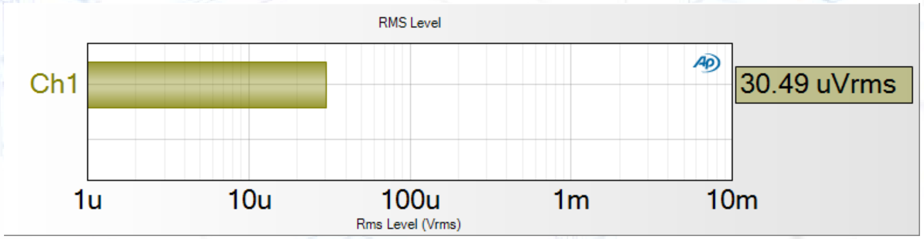
Class D (add PRE-analyzer filter)



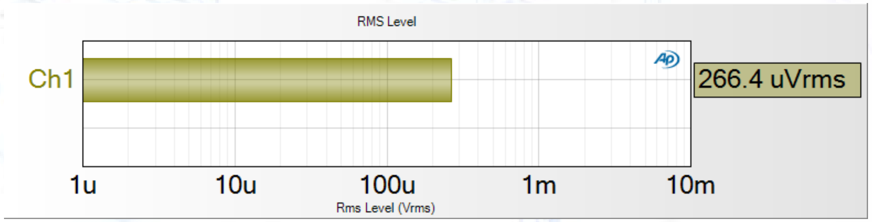
Noise (3)

- Class D results shown here were made with both an internal device filter and with an external PRE-analyzer filter.

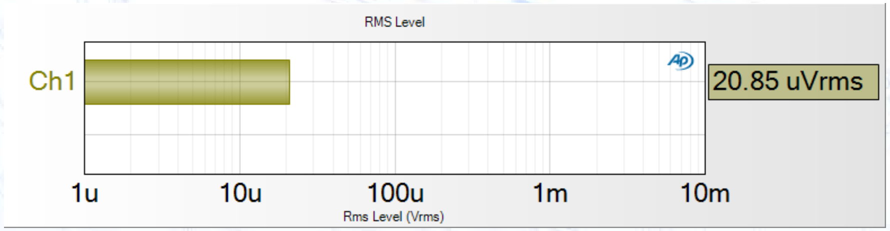
Linear (20 Hz to 20 kHz filter)



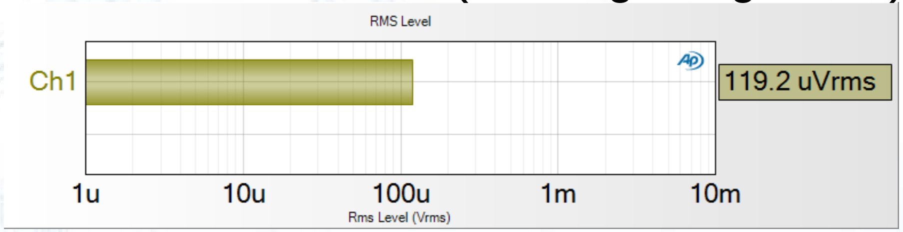
Class D (20 Hz to 20 kHz filter)



Linear (A-weighting filter)

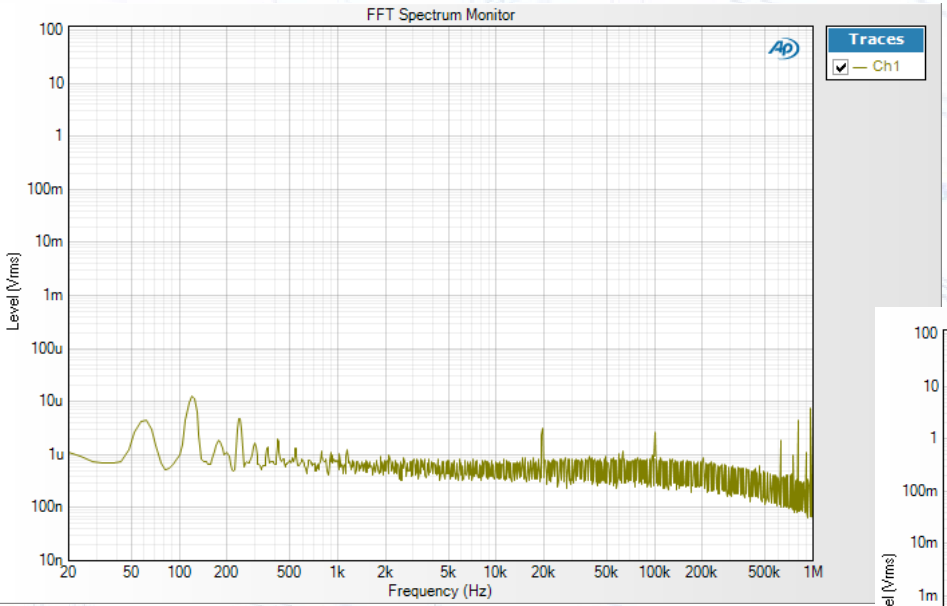


Class D (A-weighting filter)



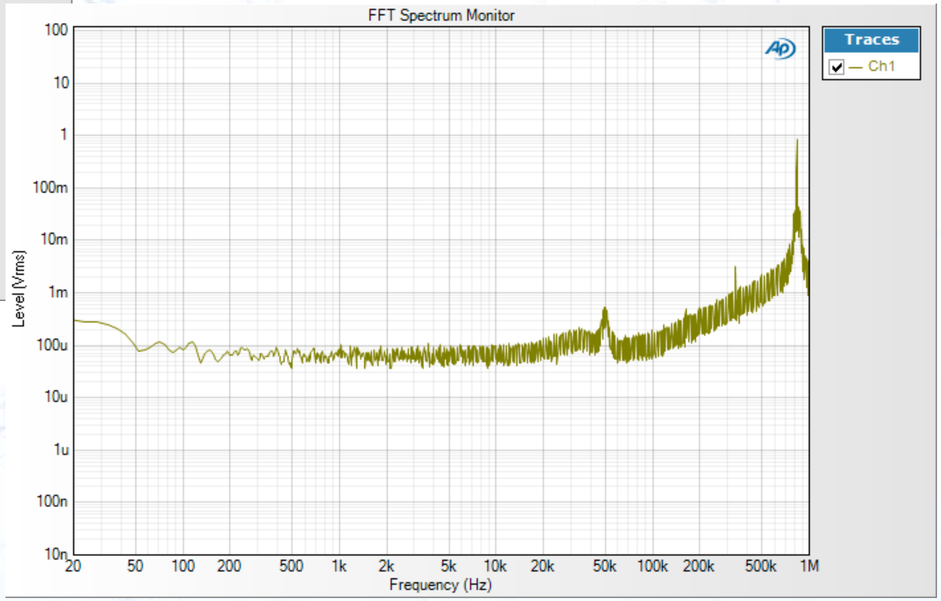
Noise (4)

FFT spectrum view.



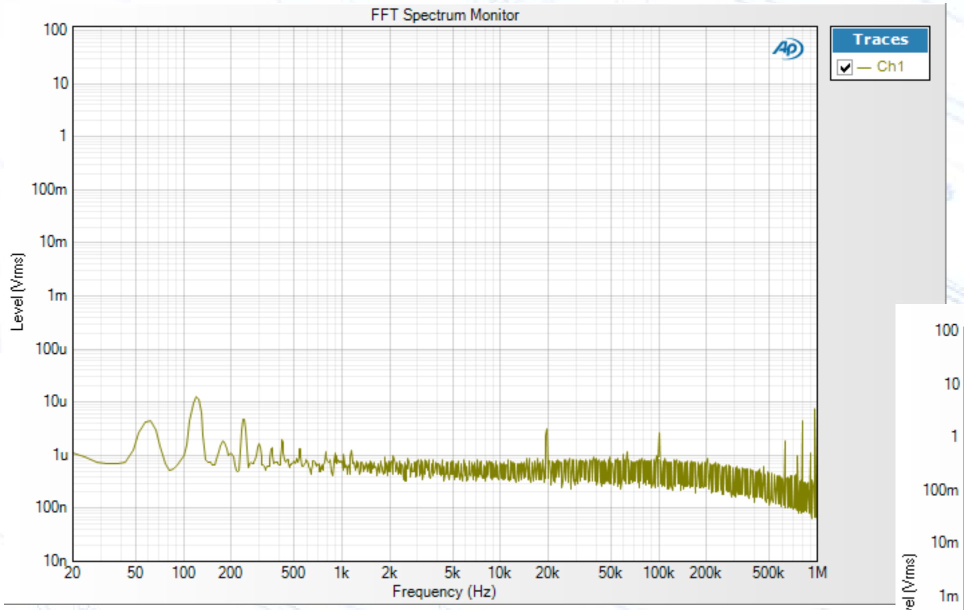
Linear, no filter.

Class D, no filter



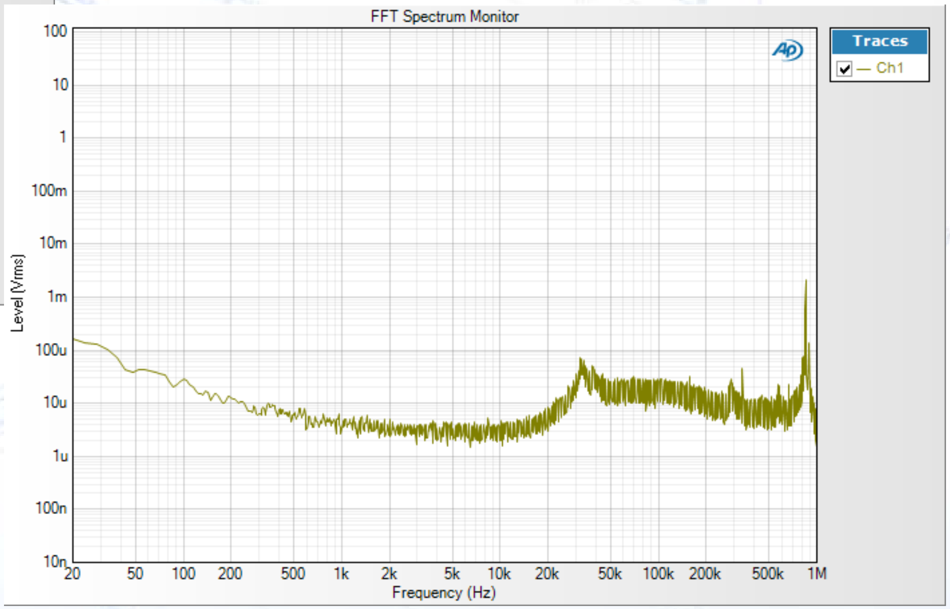
Noise (5)

FFT spectrum view.



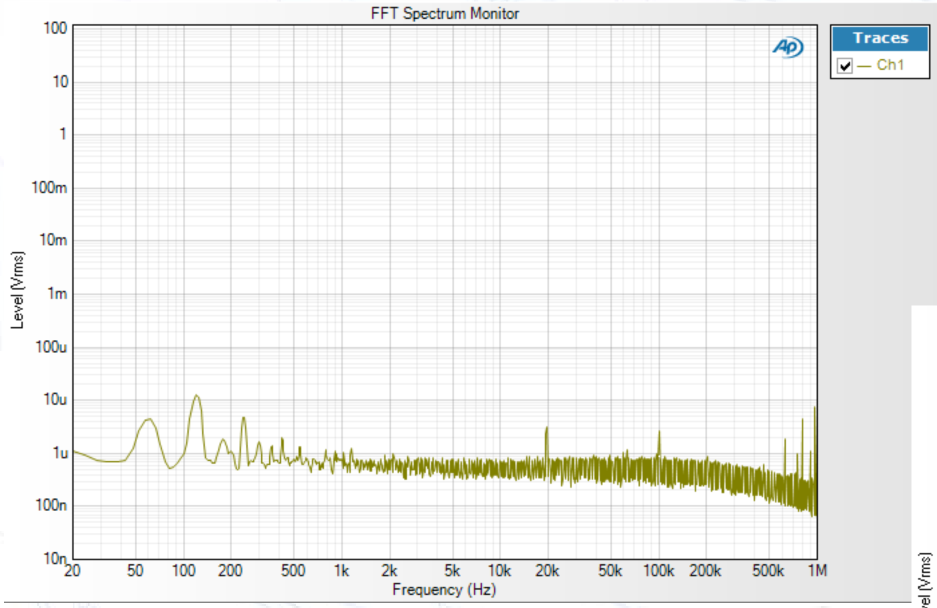
Linear, no filter.

Class D, add internal device filter



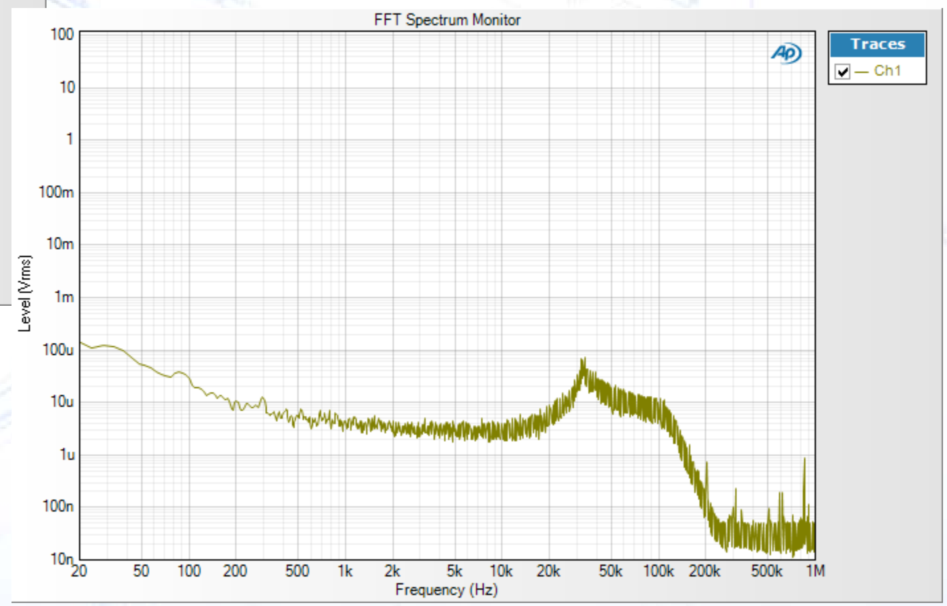
Noise (6)

FFT spectrum view.



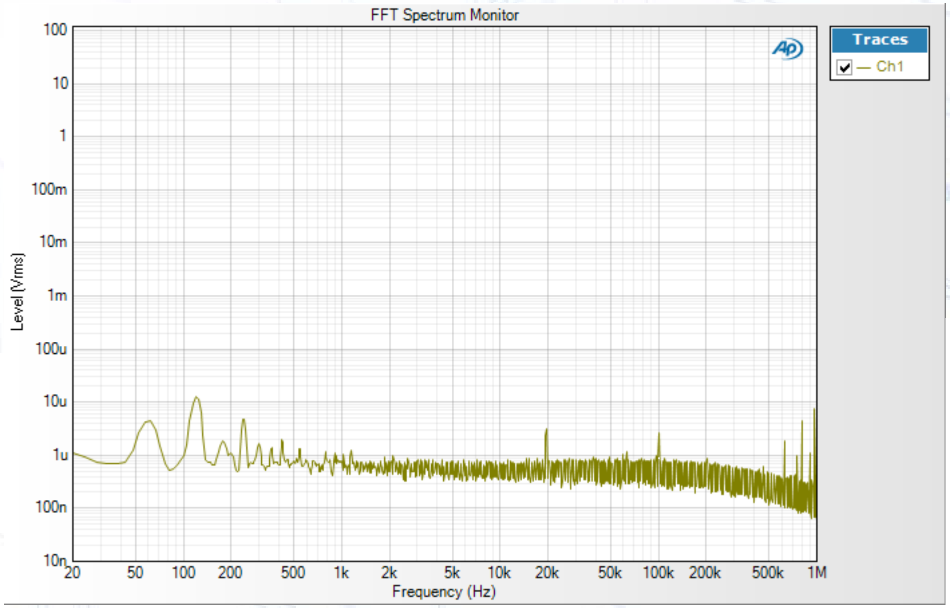
Linear, no filter.

Class D, add external PRE-analyzer filter



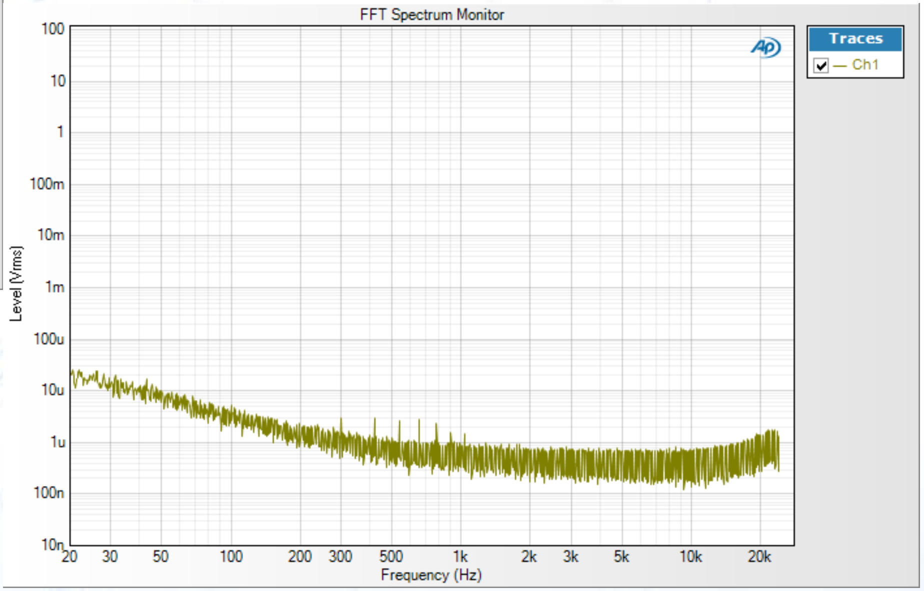
Noise (7)

FFT spectrum view.



Linear, no filter.

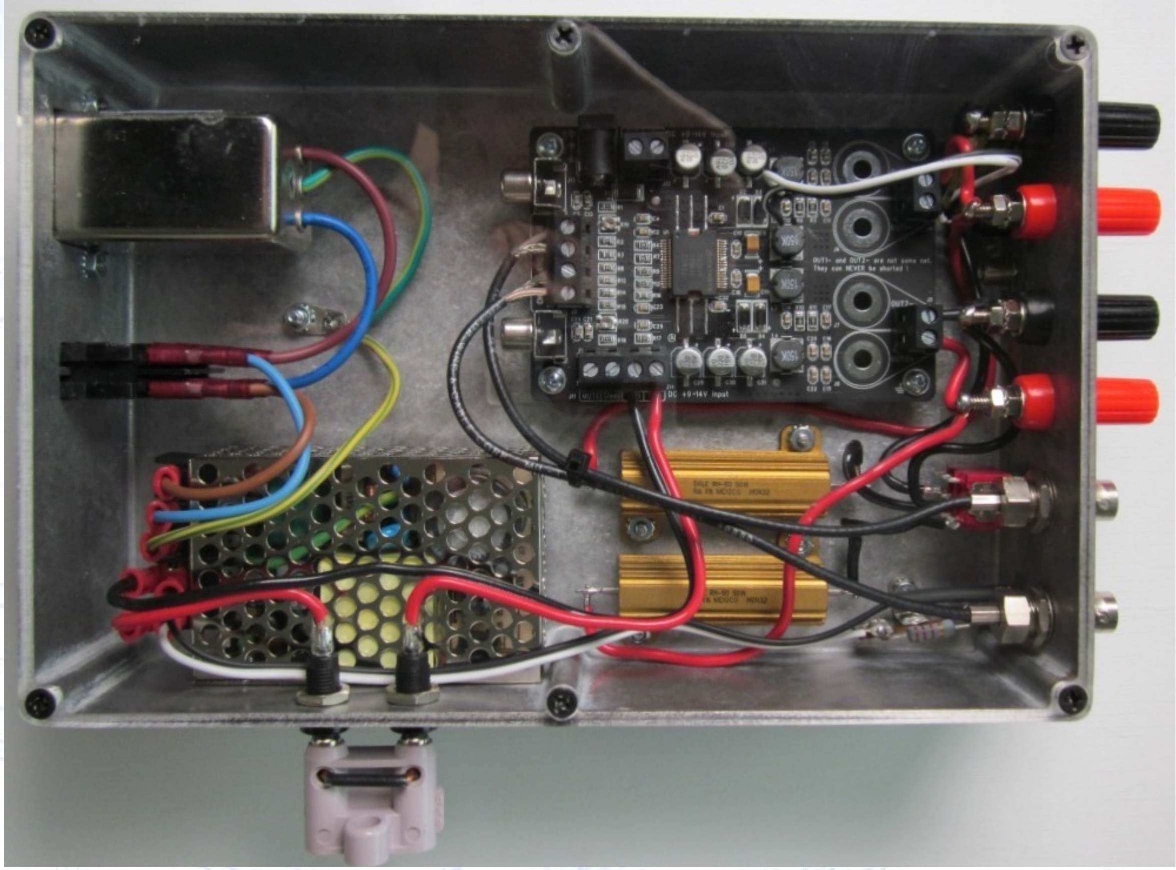
Class D, add
22 kHz low-pass filter



Demonstration DUT

- Class D amplifier (IC design)
  - 15W/channel (4Ω, 10% THD+N)
  - 10W/channel (4Ω, 0.1% THD+N)
  - Demo has 8Ω load resistors

DUT configuration

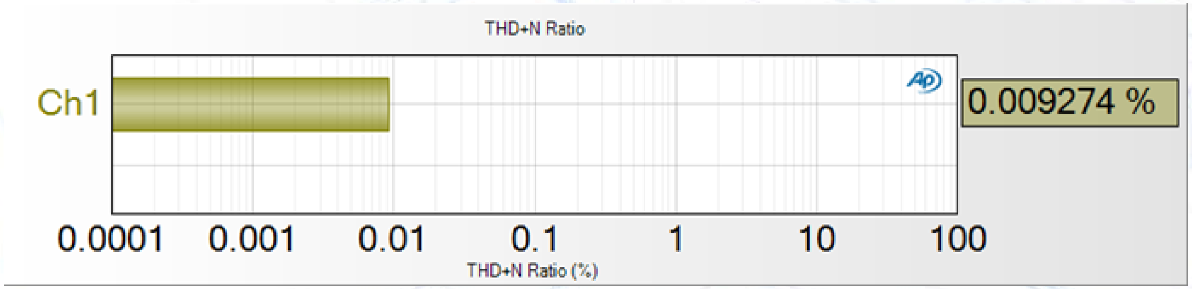


THD+N

- THD+N is a long-respected figure of merit for an audio amplifier.
- A stimulus tone is passed through the amplifier, then removed from the output signal at analysis. The residual is the sum of the noise and distortion products generated in the amplifier.
- Like noise measurements, THD+N measurements are typically bandwidth limited, and may use weighting filters.
- A THD+N vs. level sweep is also of interest.

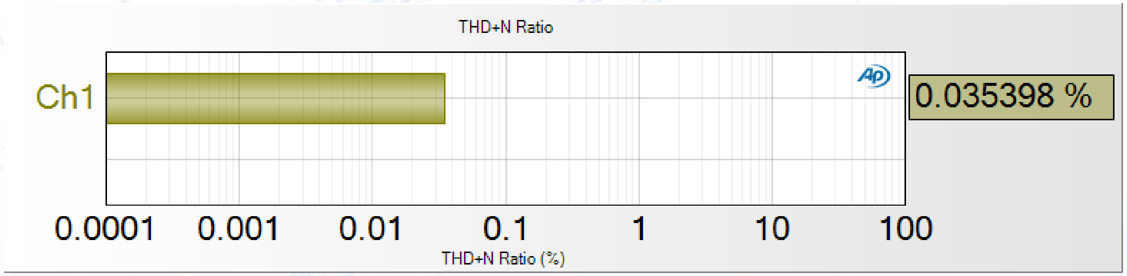
THD+N Ratio

- Class D results shown here were made with both an internal device filter and with an external PRE-analyzer filter.

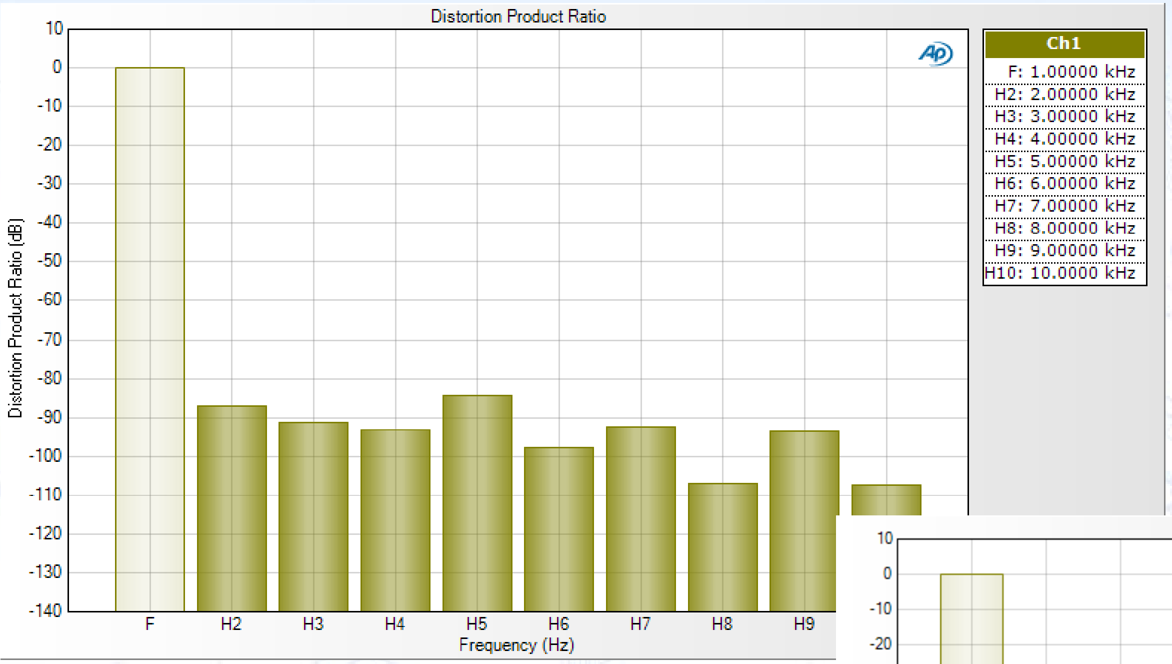


Linear, with
20 Hz to 20 kHz bandpass filter.

Class D, with
20 Hz to 20 kHz bandpass filter.

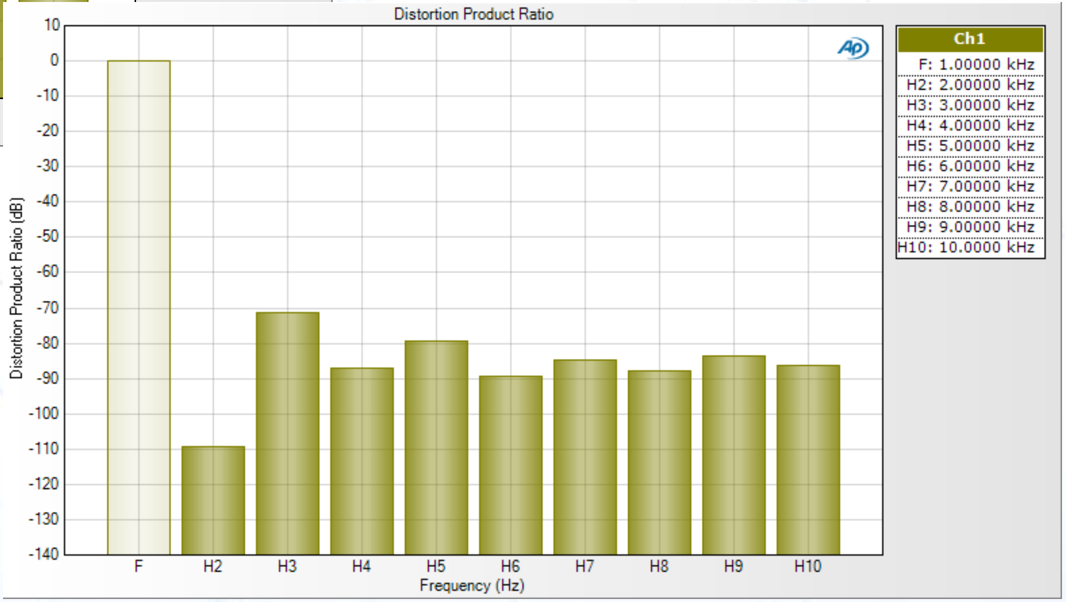


THD+N Distortion Product Ratio

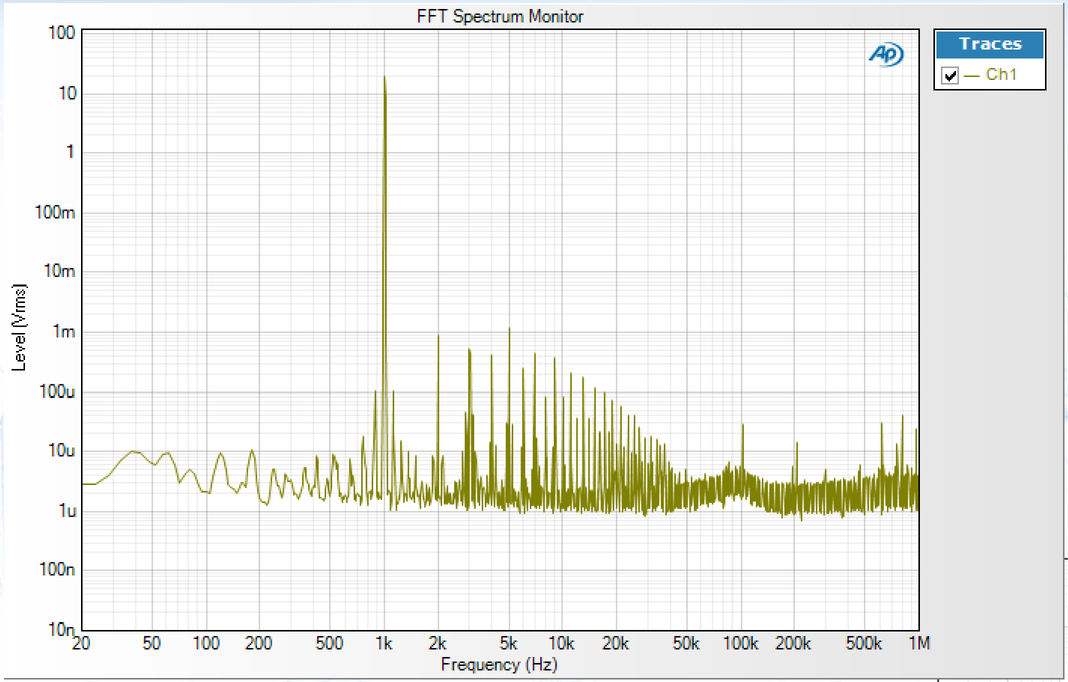


Class D, with
20 Hz to 20 kHz
bandpass filter.

Linear, with
20 Hz to 20 kHz
bandpass filter.

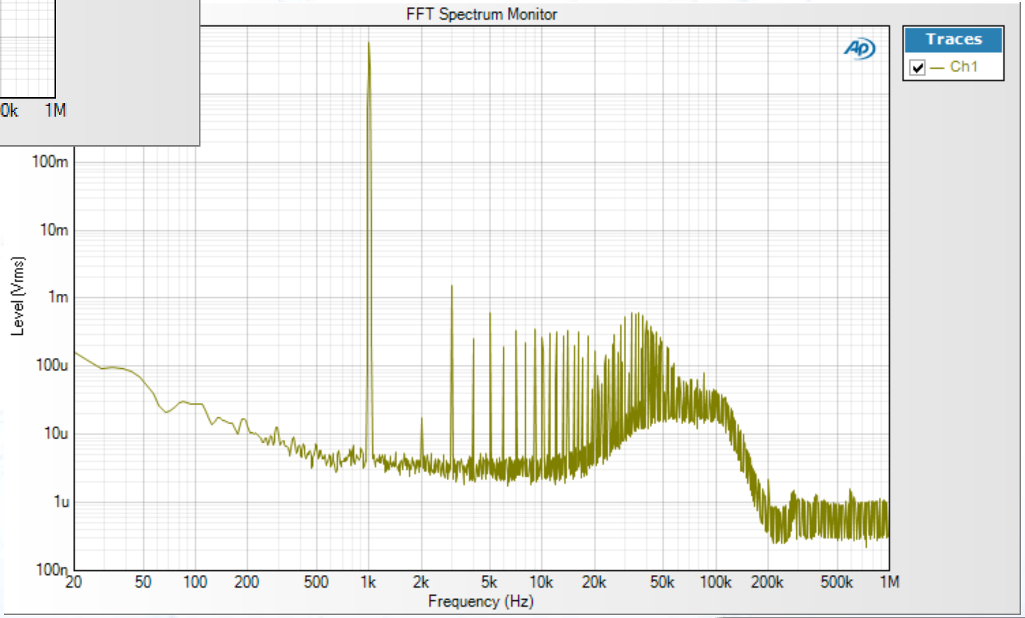


THD+N Spectrum, 1 MHz BW



Linear, with no filtering.

Class D, with device filter and external PRE-analyzer filter.



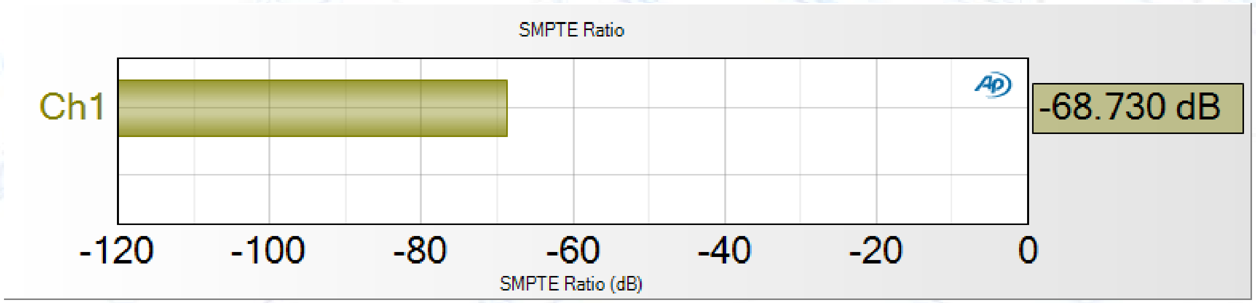
IMD Distortion tests (SMPTE and MOD)

- IMD, or intermodulation distortion, measures the products of two stimulus tones.
- SMPTE and MOD IMD measurements use a low-frequency tone (60 Hz) and a higher-frequency tone (7 kHz), remove the fundamentals and display the residuals as results.

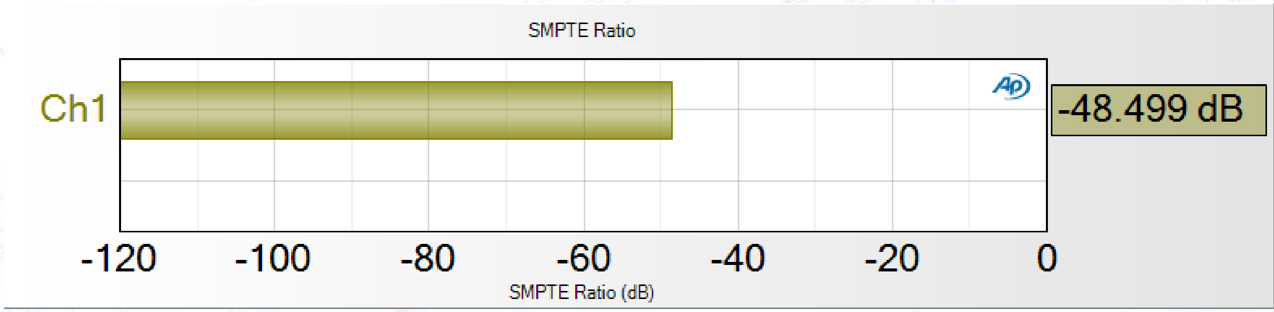
SMPTE IMD Ratio Meters

- Class D results shown here were made with both an internal device filter and with an external PRE-analyzer filter.

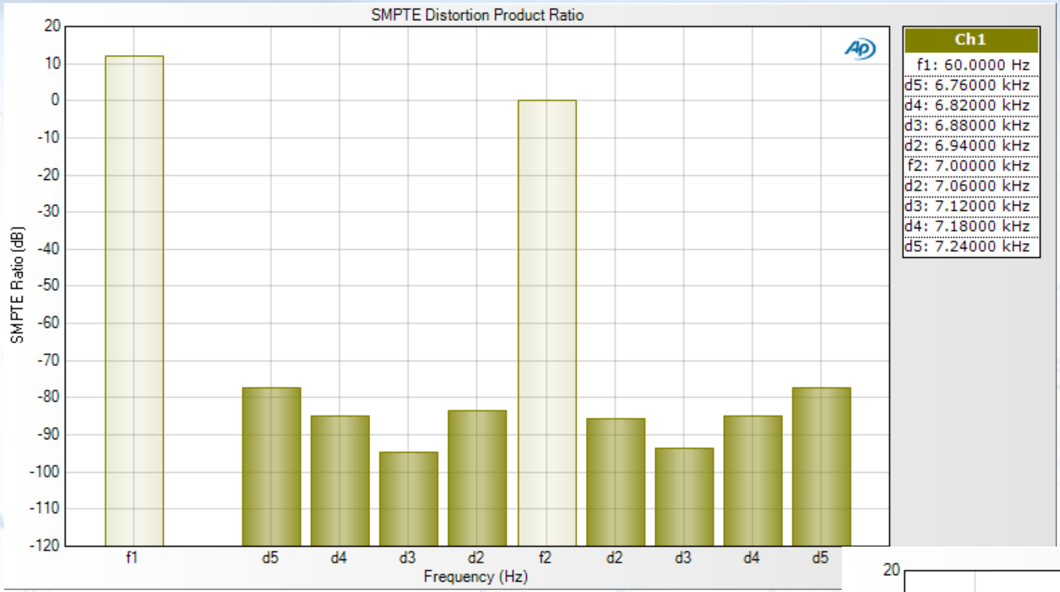
Linear



Class D

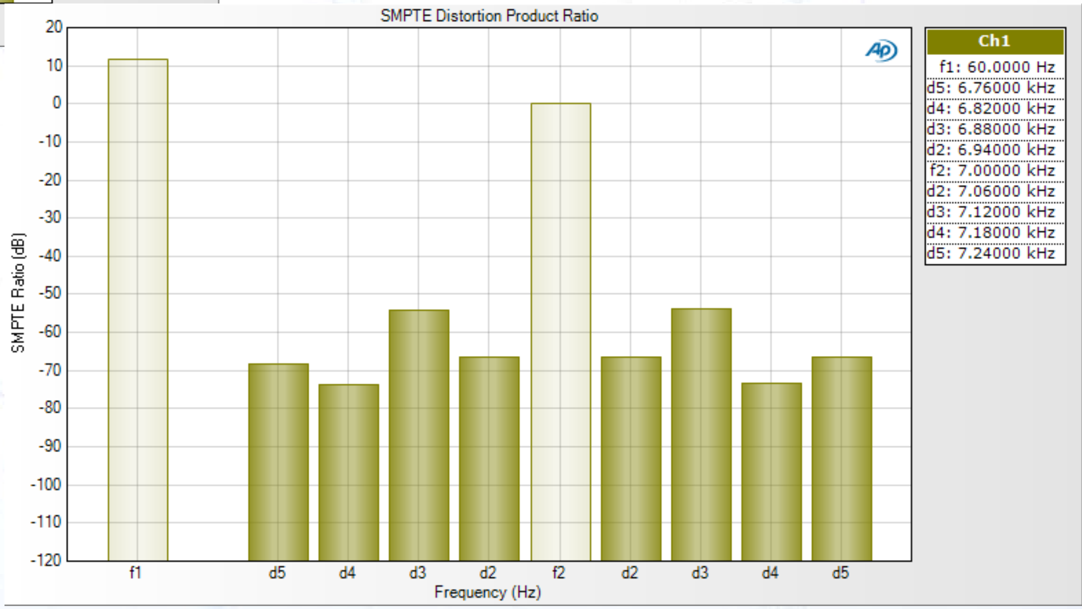


SMPTE IMD Distortion Products Ratio



Class D, with device filter and external PRE-analyzer filter.

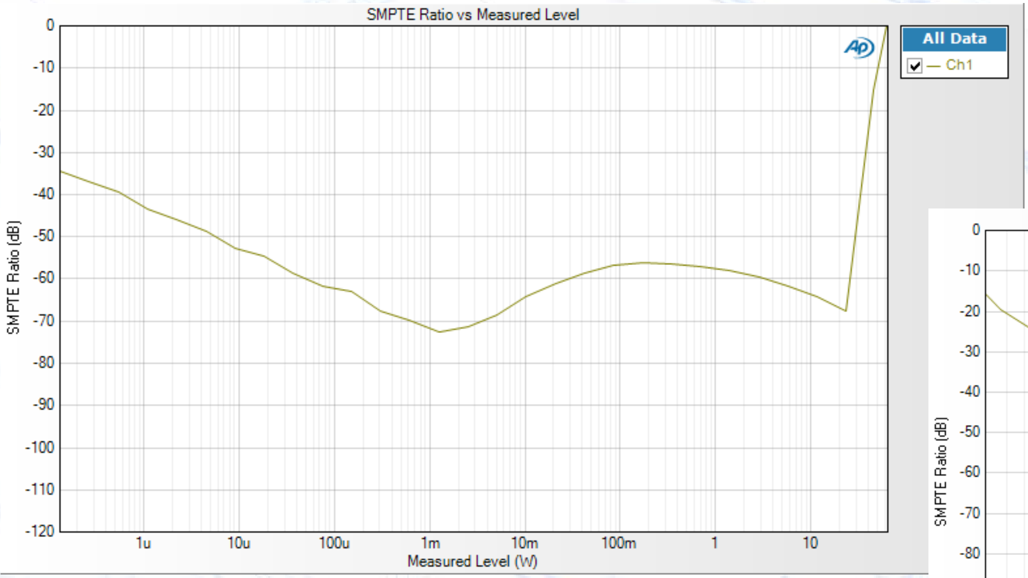
Linear, with no filtering.



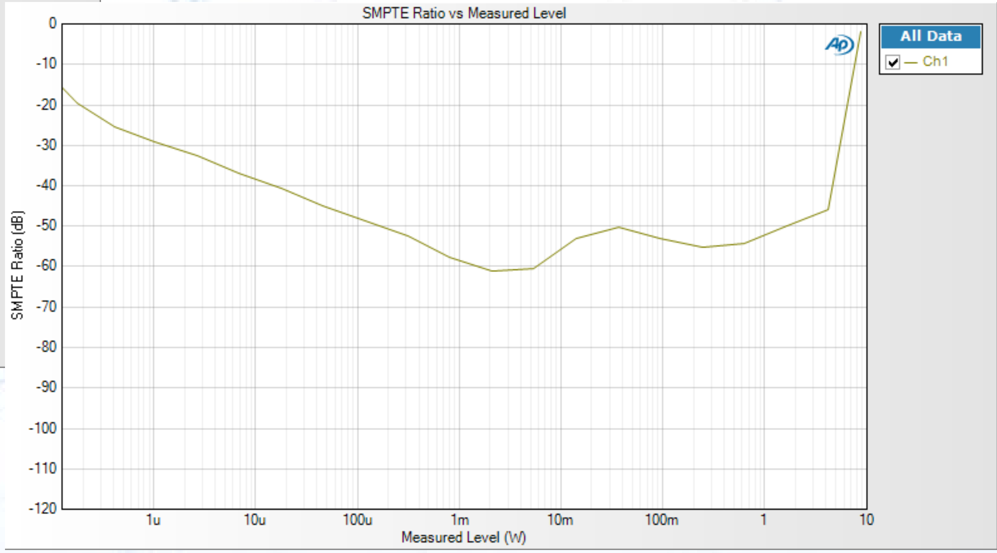
SMPTE IMD Ratio Level Sweep

- Class D results shown here were made with both an internal device filter and with an external PRE-analyzer filter.

Linear



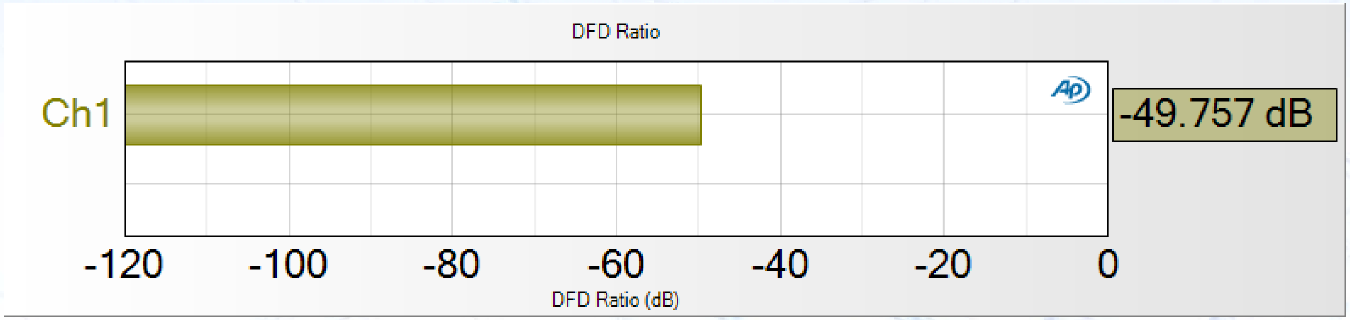
Class D



DFD and Twin Tone IMD testing

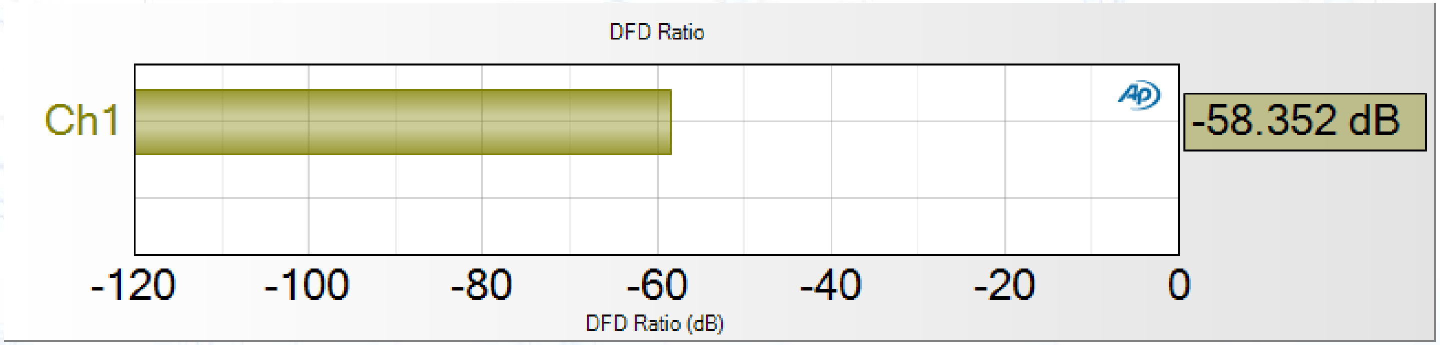
- When investigating distortion above 10 kHz, harmonic products fall above the audio bandwidth and are often beyond the typical THD+N measurement bandwidth.
  High-frequency twin-tone IMD tests such as DFD are therefore very useful to investigate distortion in the upper range of the audio bandwidth.

DFD Distortion Ratio Meters

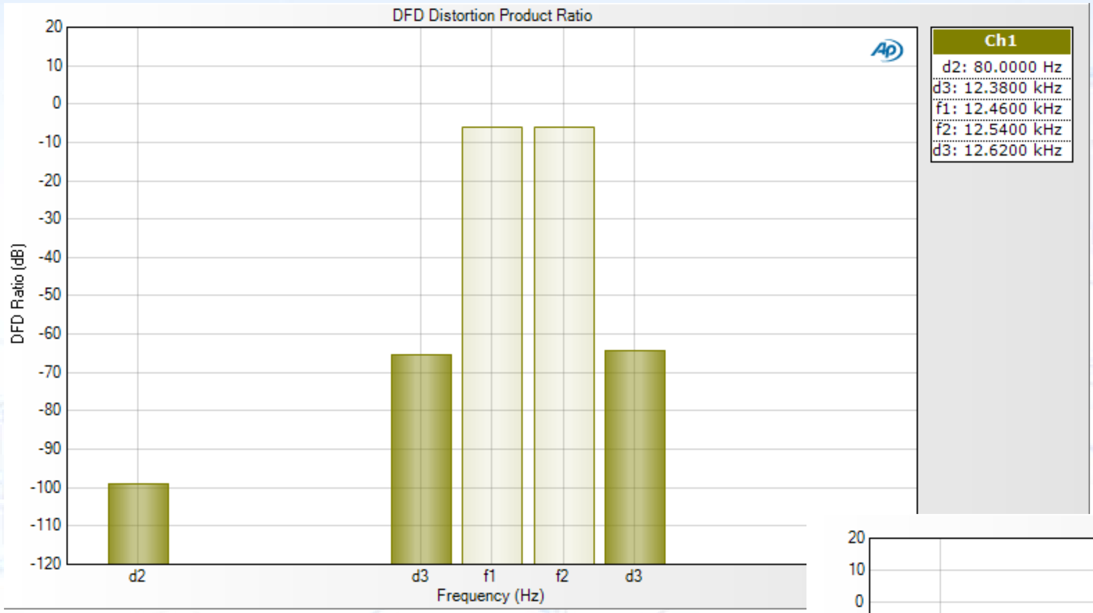


Linear, with no filtering.

Class D, with
device filter and external
PRE-analyzer filter.

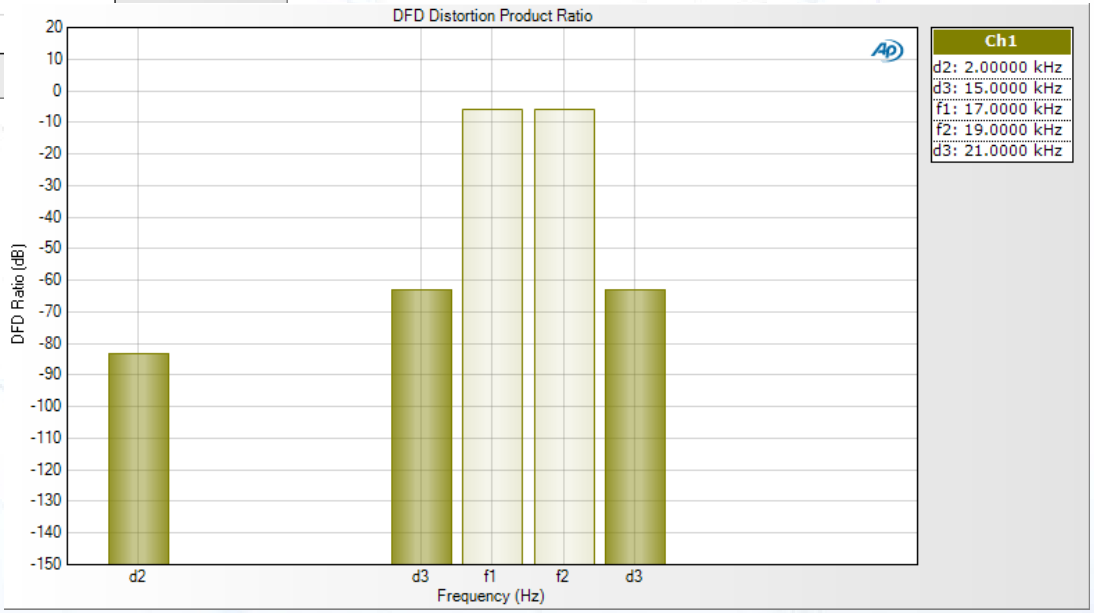


DFD Distortion Product Ratio

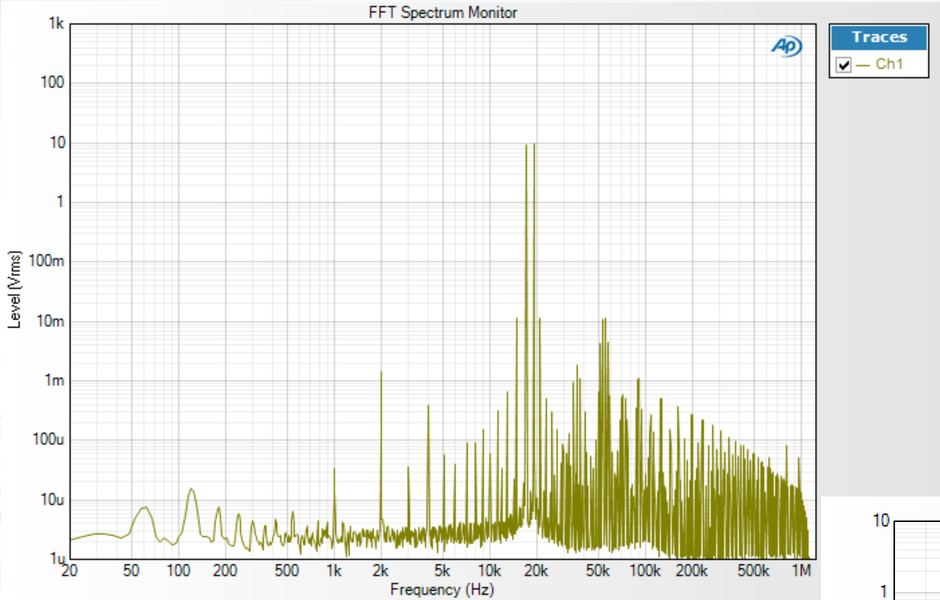


Linear, with no filtering.

Class D, with
device filter and external
PRE-analyzer filter.

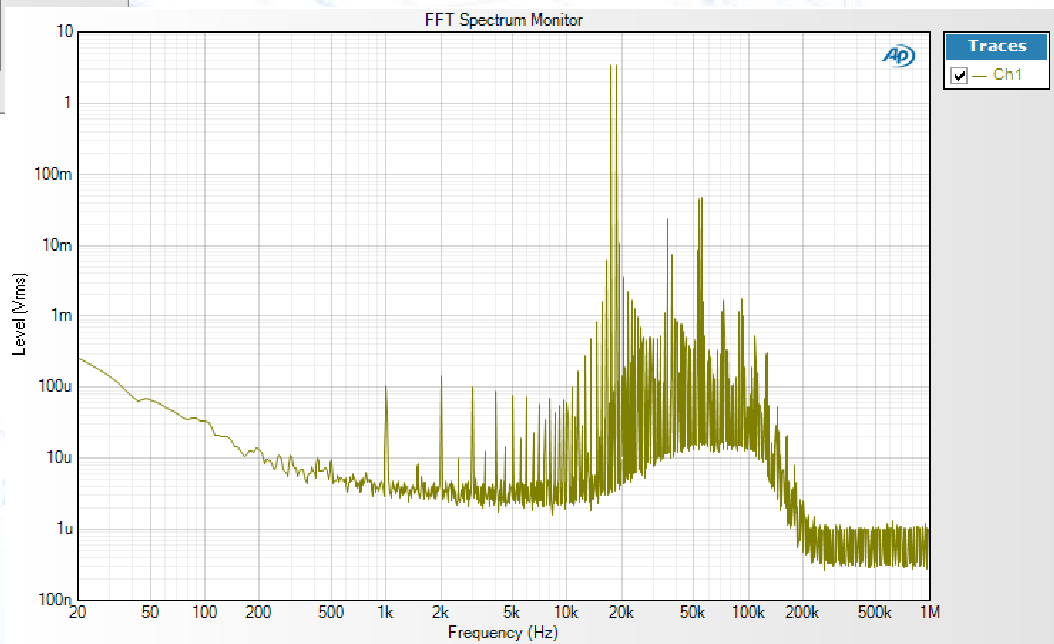


DFD Spectra, 1 MHz bandwidth

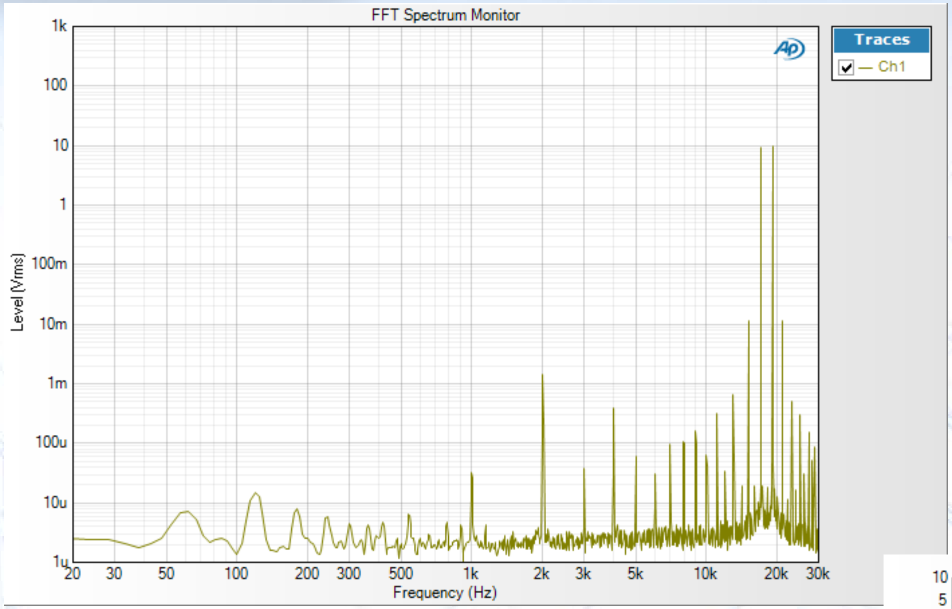


Linear, with no filtering.

Class D, with device filter and external PRE-analyzer filter.

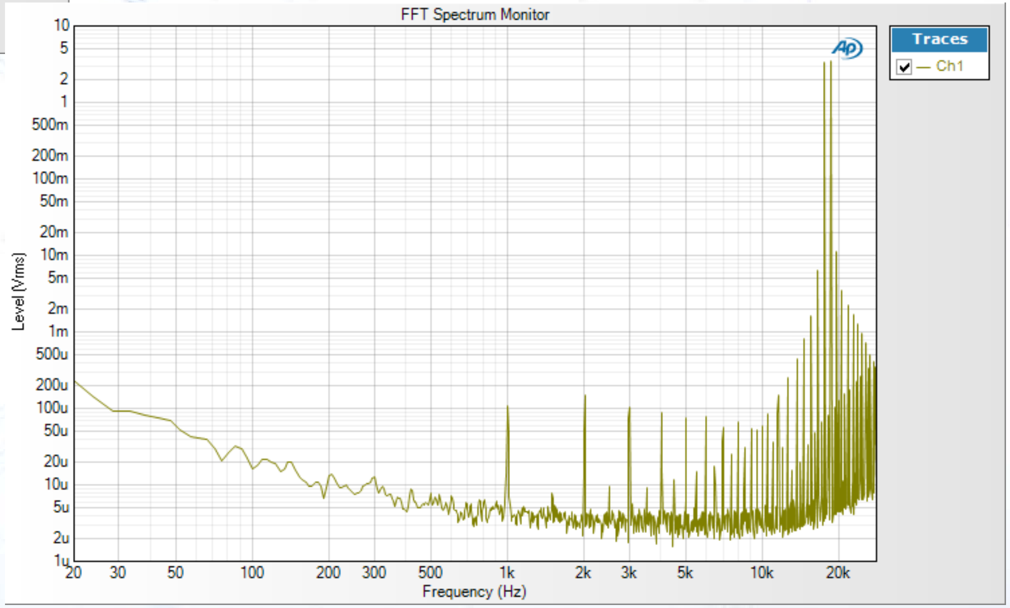


DFD Spectra, 45 kHz bandwidth



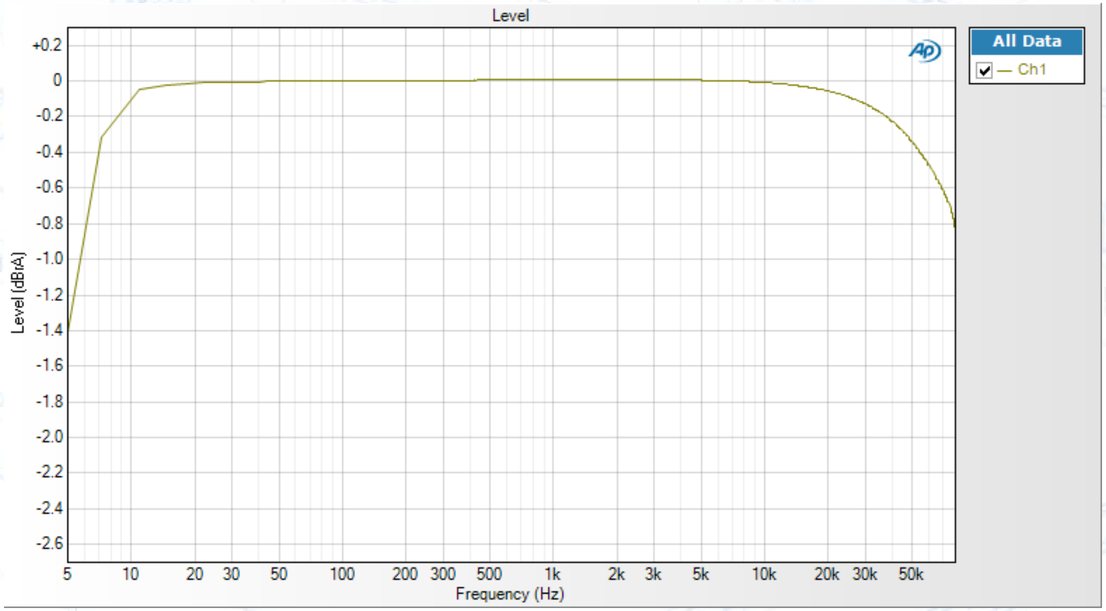
Linear, with no filtering.

Class D, with
device filter and external
PRE-analyzer filter.



Frequency Response

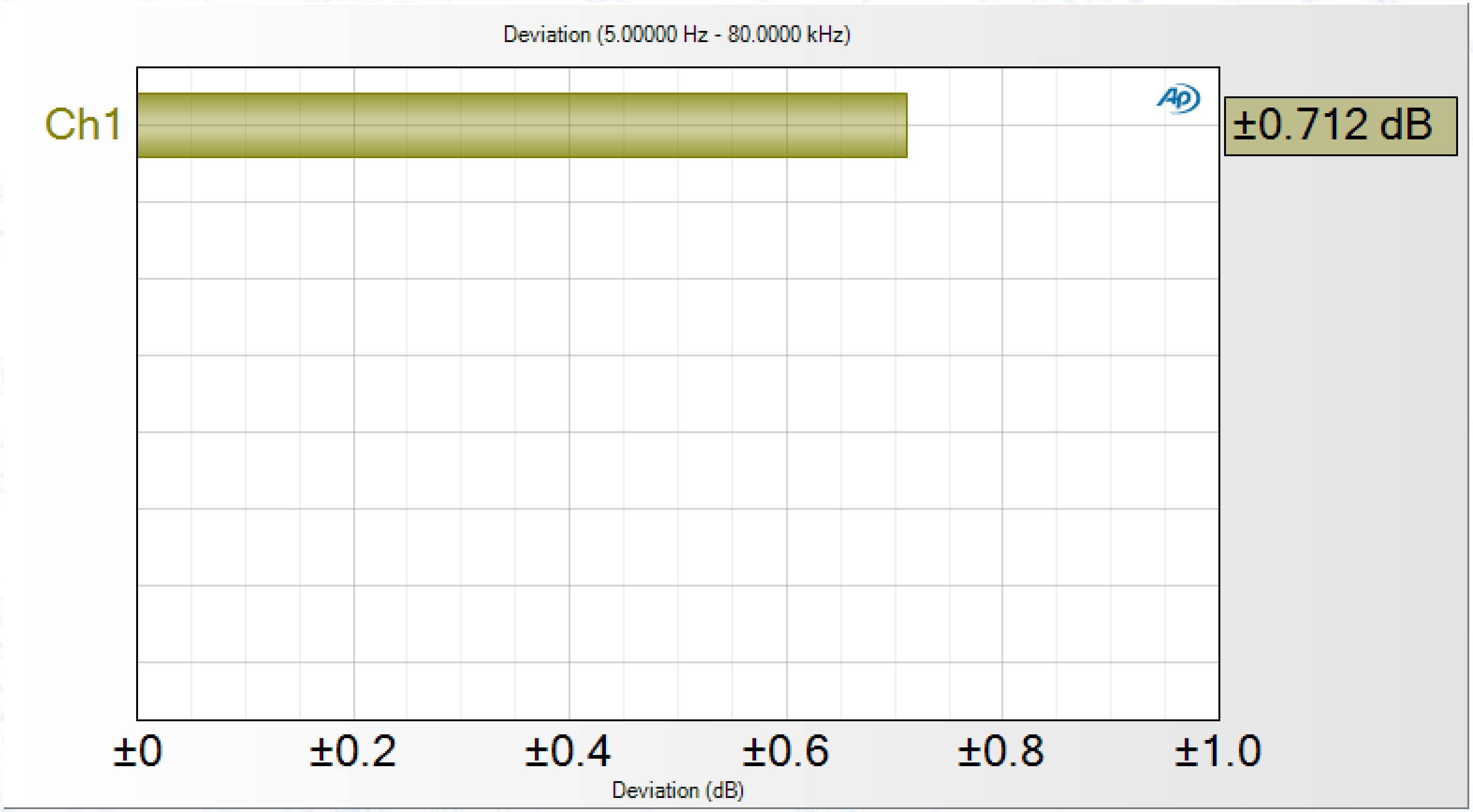
- A frequency response measurement reports the output levels of a DUT when stimulated with different frequencies of known level.



- For Class D amplifiers, the external PRE-analyzer filter should remain in place, but the sharp-cutoff measurement filter should be disabled.

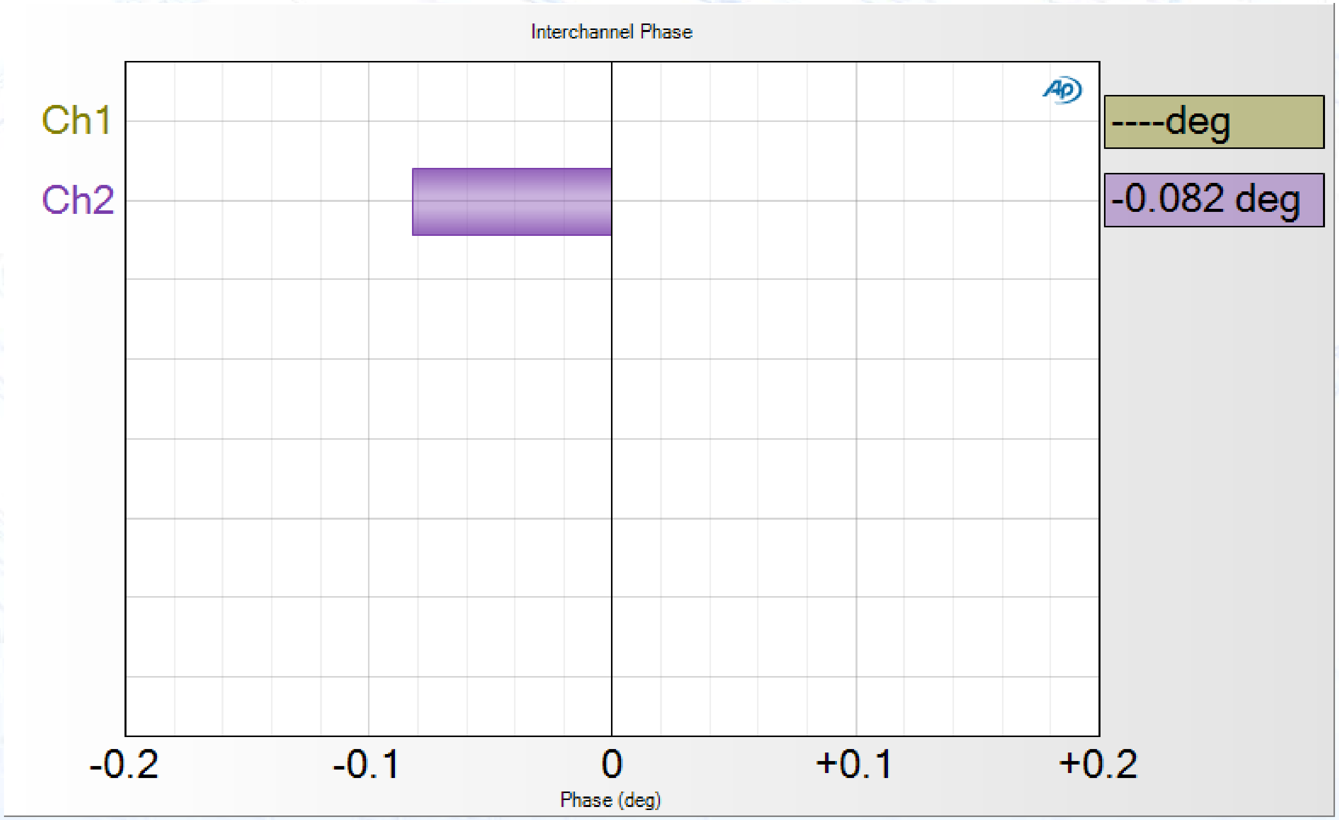
Frequency Response Deviation

- The deviation result reports the maximum range of frequency response deviation across a defined bandwidth (usually 20 Hz to 20 kHz).



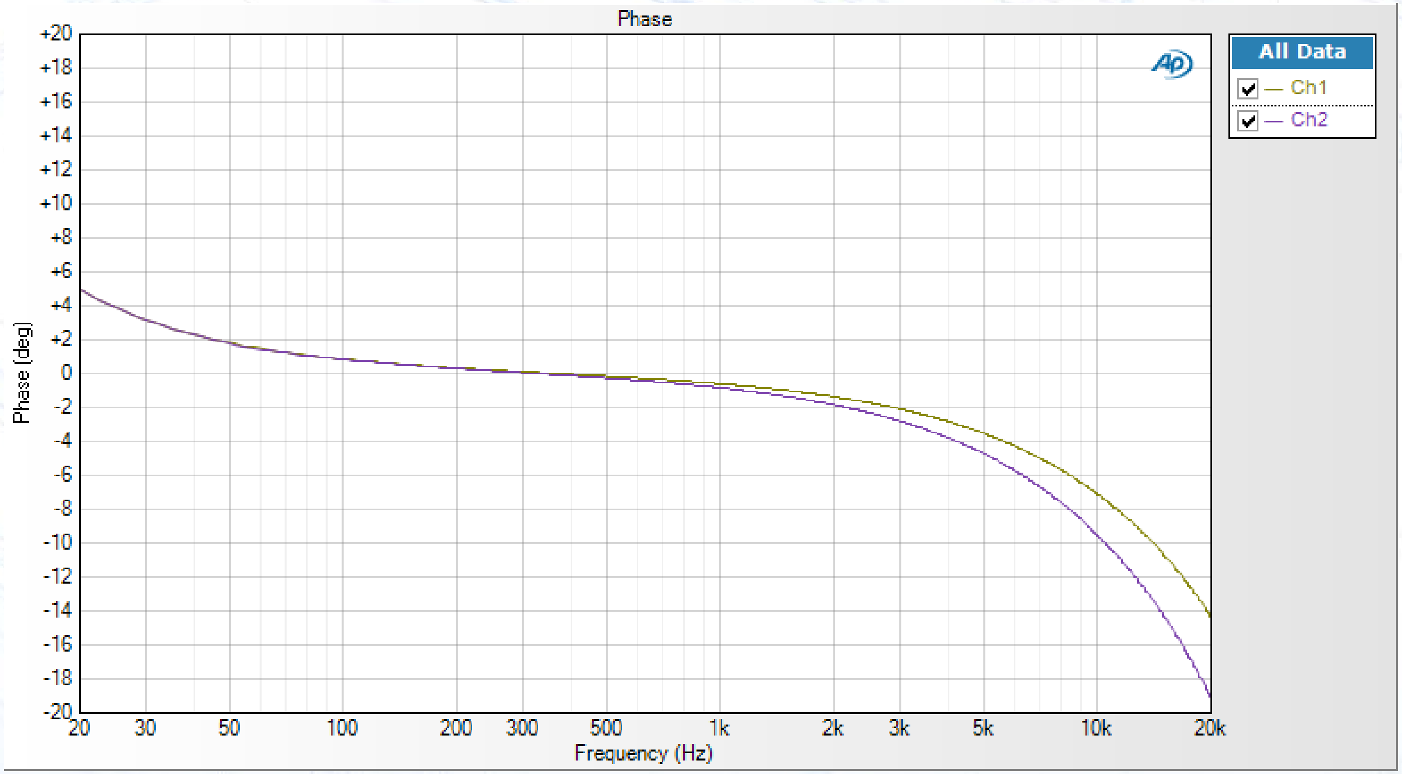
Phase

- Phase is typically measured between device channels, if appropriate. The interchannel phase (with channel 1 as the reference) is shown here.
- The input / output phase relationship of a device may also be of interest.



Phase response sweep

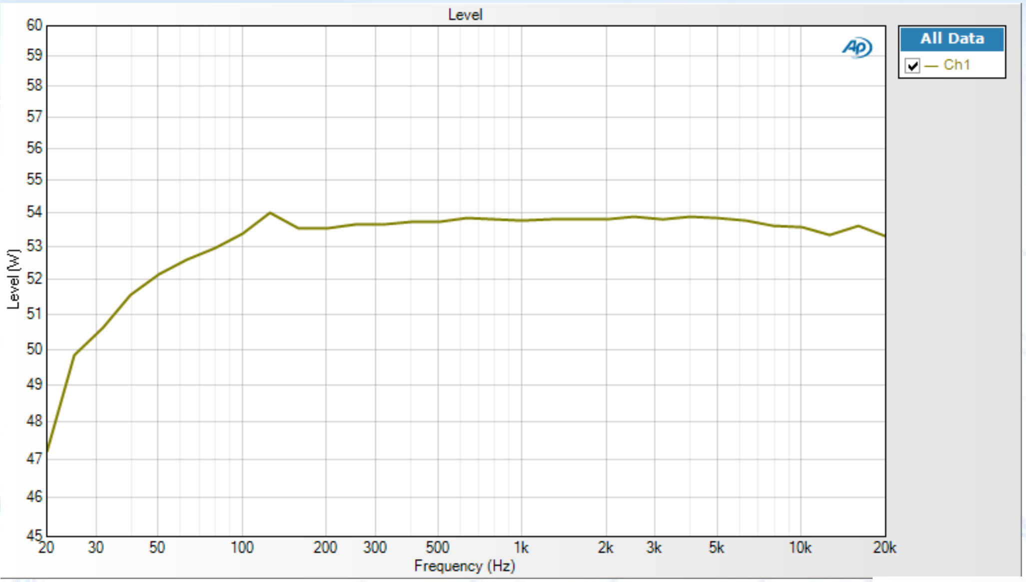
- Phase shift varies with frequency, and it is not uncommon to make phase measurements at several frequencies or to plot the phase response of a frequency sweep.



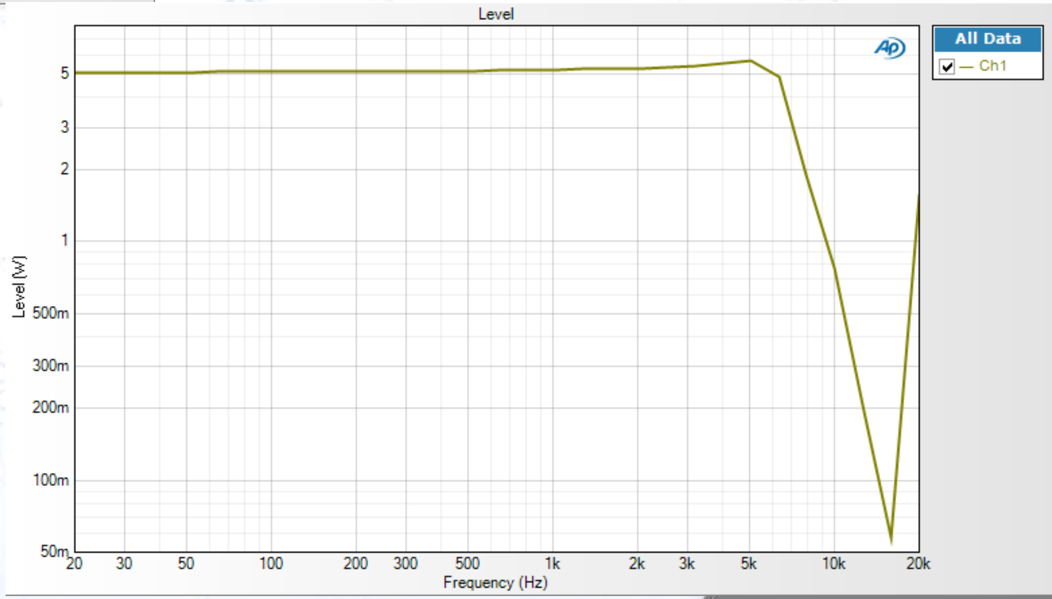
Maximum Output Level

- The maximum output level (MOL) of an amplifier is usually measured at 1% THD+N, connected to the rated load.
- A frequency sweep regulated to 1% THD+N is a useful measurement.
- In audio amplifiers, the maximum output level is often referred to as the maximum output power.

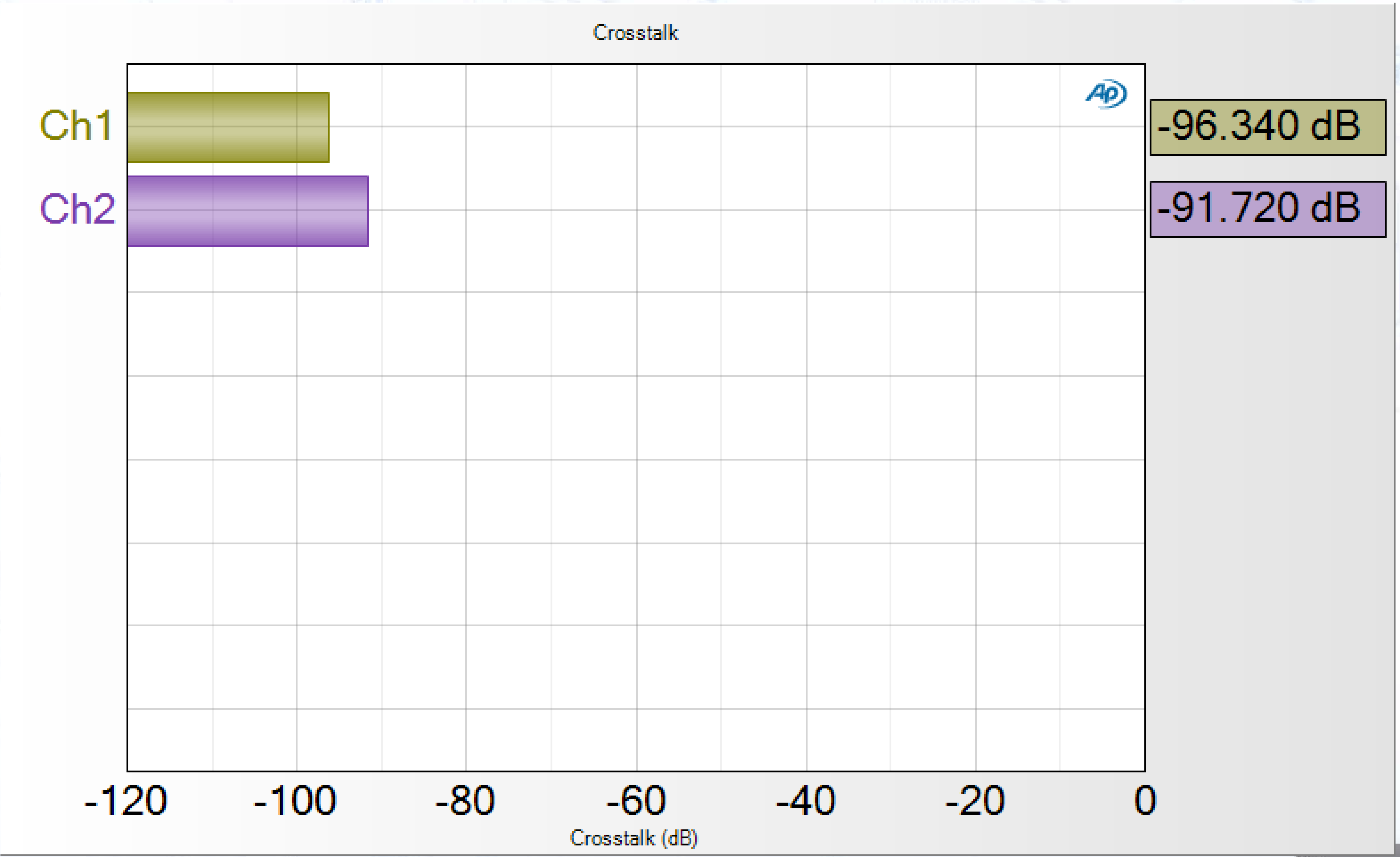
Maximum output level



- These sweeps have been regulated to 1% THD+N.

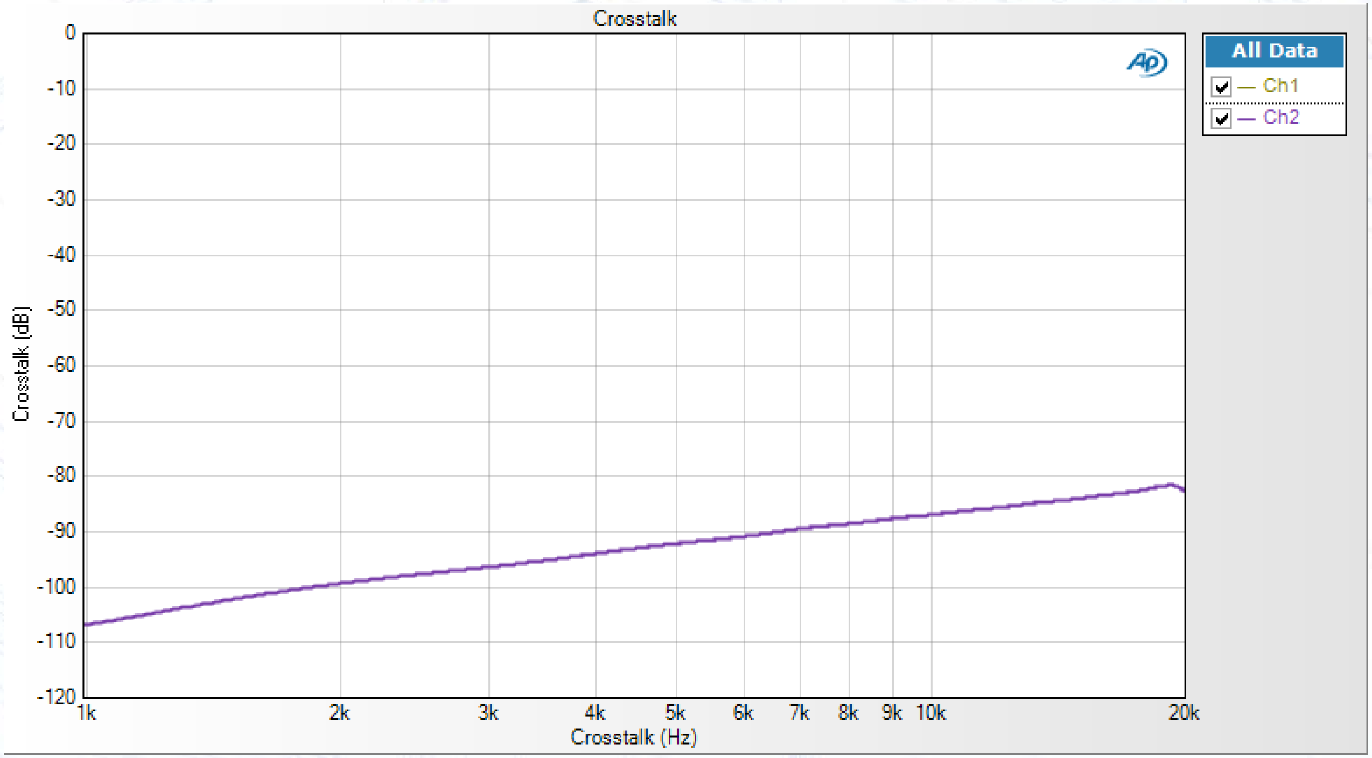


Crosstalk


Crosstalk
Ch1
Ch2
-96.340 dB
-91.720 dB
-120
-100
-80
-60
-40
-20
0
Crosstalk (dB)

Crosstalk vs. Frequency sweep

- Crosstalk measurements are typically made at 10 kHz, but a crosstalk sweep can be useful in identifying crosstalk mechanisms.

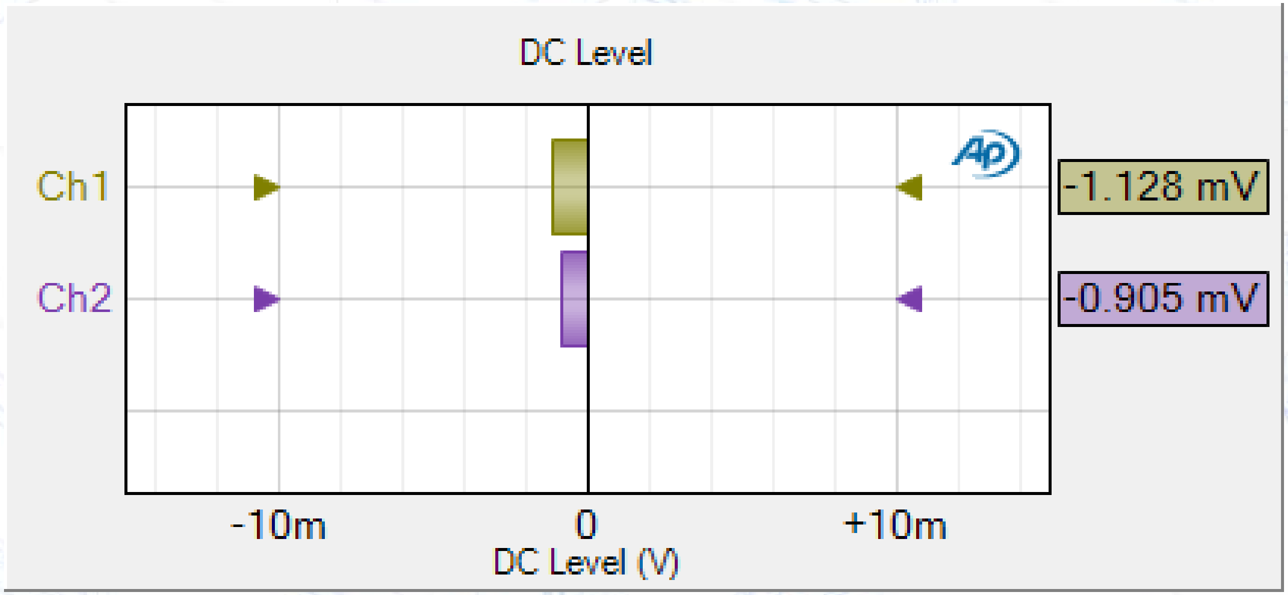


DC Offset

- DC-coupled linear audio amplifiers have a small DC voltage at each amplifier output, called the DC Offset voltage. When there is an audio (AC) voltage at the output, the audio voltage “rides” (is offset by) the DC voltage.
- A small DC Offset voltage is acceptable, but it must be measured and verified to be within limits. Large DC offsets will affect system performance and can damage components.

DC Level Meter (offset)

- The small results shown here are typical. Analyzer limits have been set at ±10 mV.



Efficiency

- Amplifier efficiency is the ratio of the output power delivered to the load, to the operating power supplied to the amplifier.
- For a dc-powered amplifier, the input power is the product of the power supply voltage and the drawn current. The current can be determined by measuring the voltage drop across a small known resistor in series with the supply current.
- For an ac-powered amplifier, a power meter (watt meter) must be used to determined the supplied power.

Power Supply Rejection Ratio

- The Power Supply Rejection Ratio (PSRR) of an amplifier is a measure of a device's ability to reject noise from the supply used to power it. It is defined as the ratio of the change in supply voltage to the corresponding change in output voltage of the device.

T E C H N O T E

Application and Technical Support for Audio Precision Users

TN106

Audio precision

Measuring Power Supply Rejection Ratio (PSRR)

- [x] 2700 Series
- [x] ATS-2
- [x] APx500 Series

By Joe Begin and Adam Liberman

About This Technote

In this technote we describe and compare two different methods to measure PSRR. Then we give instructions for using the APx PSRR Measurement Utility, which simplifies the calculations and graphing on APx analyzers.

Introduction

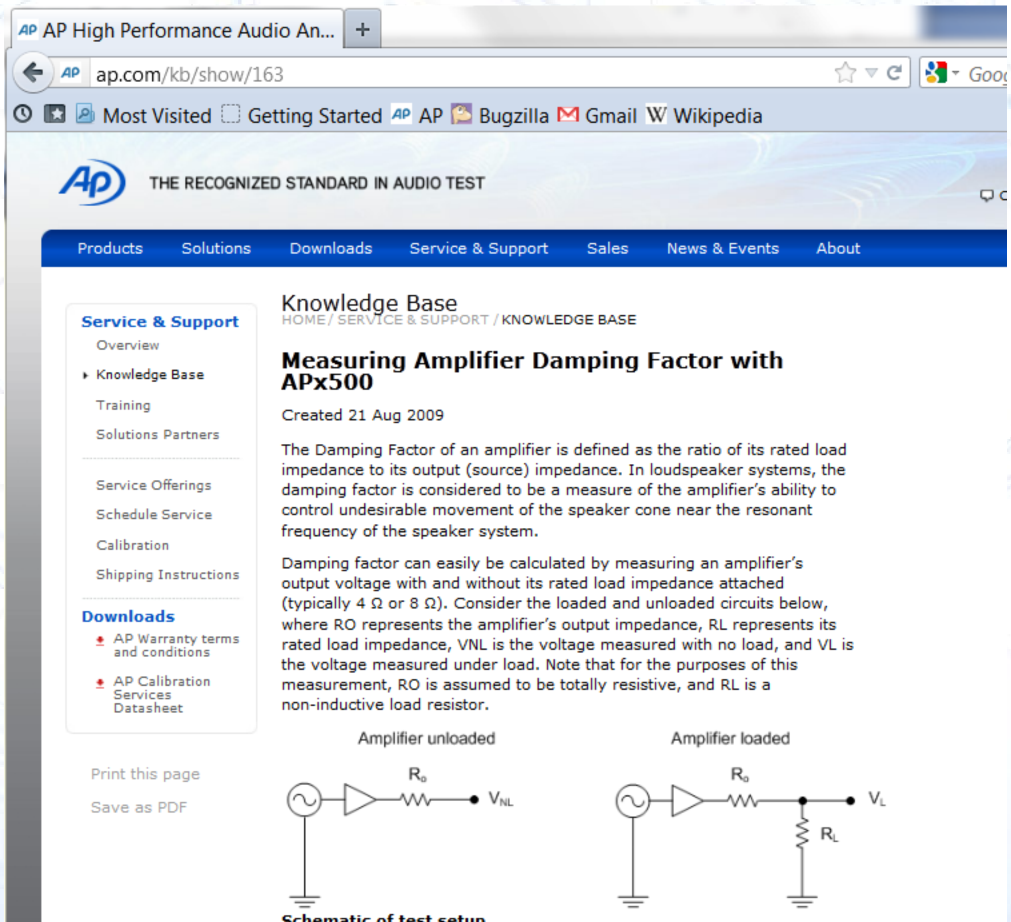
Power Supply Rejection Ratio (PSRR) is a measure of a device's ability to reject noise from the supply used to power it. It is defined as the

PSRR measurements are typically made for ICs and other functional assemblies. To measure such a device's power supply rejection, we need to insert an AC signal (ΔV_{IN}) in series with the DC voltage from the supply and examine the device's output (ΔV_{OUT}) for the presence of the signal. It is often desirable to measure PSRR over a range of frequencies and to produce a spectrum plot of PSRR versus frequency.

PSRR Measurement Methods

Damping Factor

- The Damping Factor of an amplifier is defined as the ratio of its rated load impedance to its output (source) impedance.



Summary

- Audio power amplifiers can be extensively tested using an audio analyzer, load resistors and mains power and watt meters.
- With the appropriate filters, Class D audio amplifiers can be tested in the same way as linear audio amplifiers.

Demo