

*AES bijeenkomst  
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heynen



# MEASURING CLASS-D AMPLIFIERS

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## *Not Your Traditional Audio!*

- Output is string of width modulated pulses
- Slew rates can easily exceed 1000 V/usec even with low amplitude audio signals
  - *must be limited to prevent EMI problems*
- Loudspeakers (and the human ear) do not appear to exhibit any unusual sensitivity or non-linearity with respect to signal slew rate, **HOWEVER...**

## *Test Equipment can be VERY Sensitive to Input Signal Slew Rate*

- Low noise & distortion (“audio-worthy”) op-amps become very non-linear above 5-10 V/usec
- Wideband oscilloscope and DMM input designs do not give adequately low noise and distortion performance—*by several orders of magnitude!*
- Audio analyzers simply should not be expected to work properly with Class-D amp output signals!

## *A Low-Pass Filter is Essential prior to the Input of an Audio Analyzer*

- Must be PASSIVE
  - *active design would have same slew rate limitations!*
- Simple R-C filters have been recommended in a Texas Instruments Application Note
  - *not sharp enough*
  - *TI filter values give -1.7 dB response at 20 kHz*
- A multi-stage LCR filter is desirable

## *Why the LC Filter inside most Class-D Amplifiers may not be sufficient*

- Real world inductors have self-resonant frequencies above which they appear capacitive
  - *A single LC filter stage will always allow some fast slewing artifacts to “blow-by”*
- A series resistive element can not be used in the filter design because it must pass high power audio signals with as little loss as possible
  - *The filter in series with the audio analyzer is not subject to this limitation because of the relatively high input impedance of the analyzer*

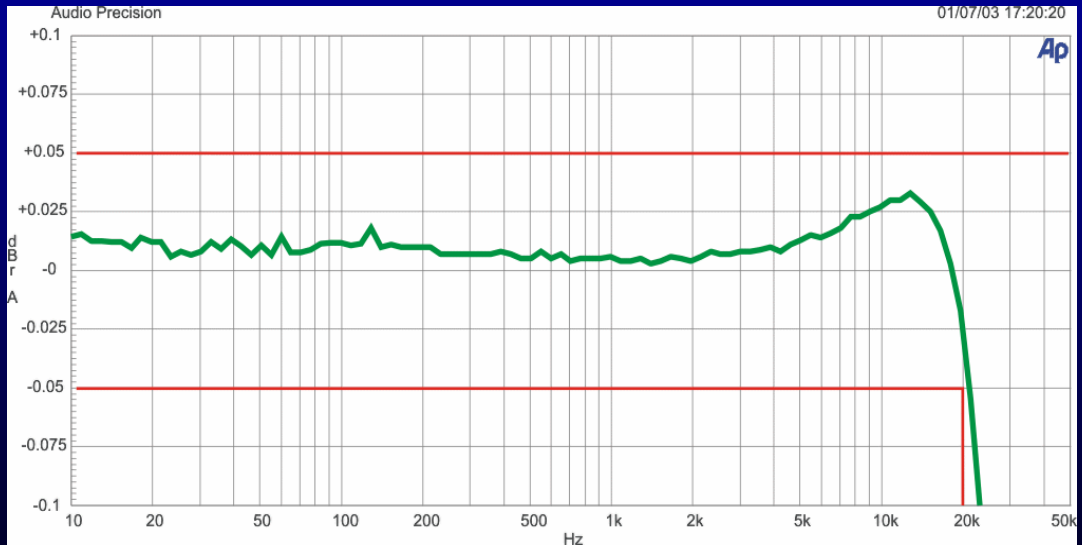
# *...The AUX-0025 Filter Accessory*



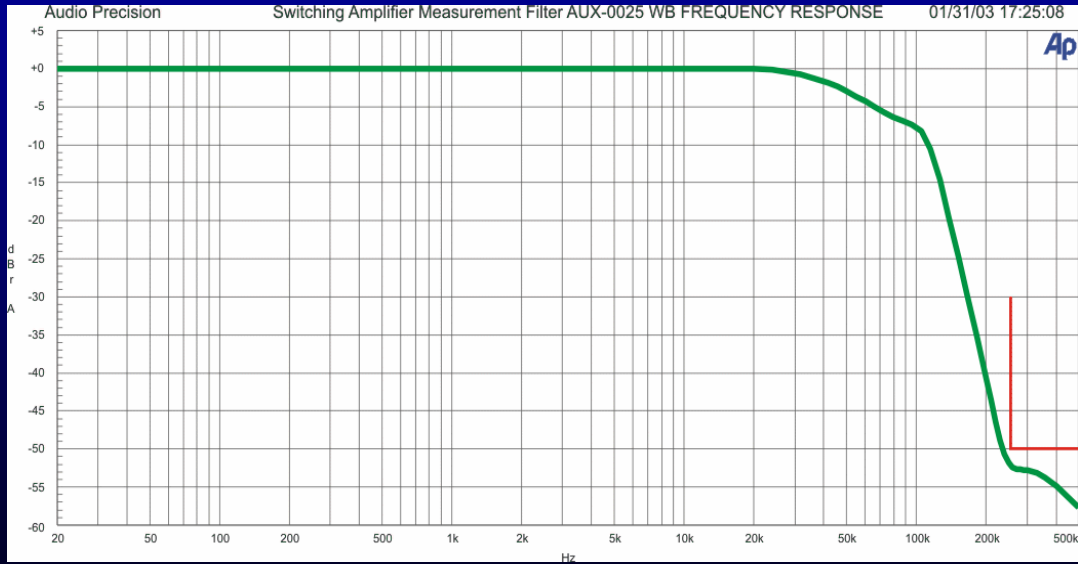
## *AUX-0025 Specifications*

- Frequency Response:  $\pm 0.05$  dB, 10 Hz to 20 kHz
- Insertion Loss:  $\approx 0.05$  dB with 100k Ohm load
- HF Rejection:  $\geq 50$  dB, 250 kHz to 20 MHz
- Inter-Channel Crosstalk:  $\leq -90$  dB at 20 kHz
- Distortion:
  - $\leq -110$  dB Harmonic (70 V<sub>pp</sub>, 1 kHz)
  - $\leq -100$  dB IMD (70 V<sub>pp</sub>, 18 kHz + 20 kHz)
- Input Impedance:  $\approx 500$  Ohm in series with 10 nF
- Maximum Input: 200 V<sub>peak</sub>

# Typical Pass-Band Response



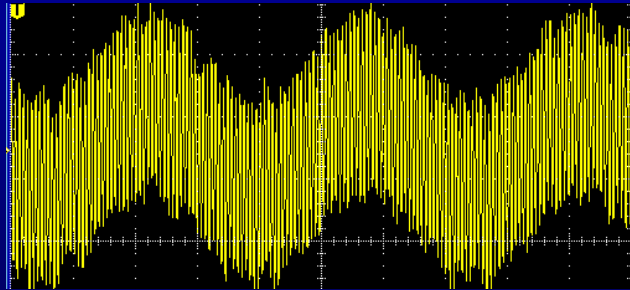
# Typical Roll-Off Characteristic



# *Typical Time Domain Effect*

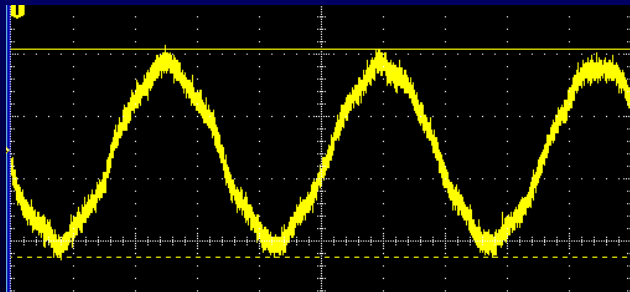
## **Raw Unfiltered Signal**

Artifacts masked by  
switching

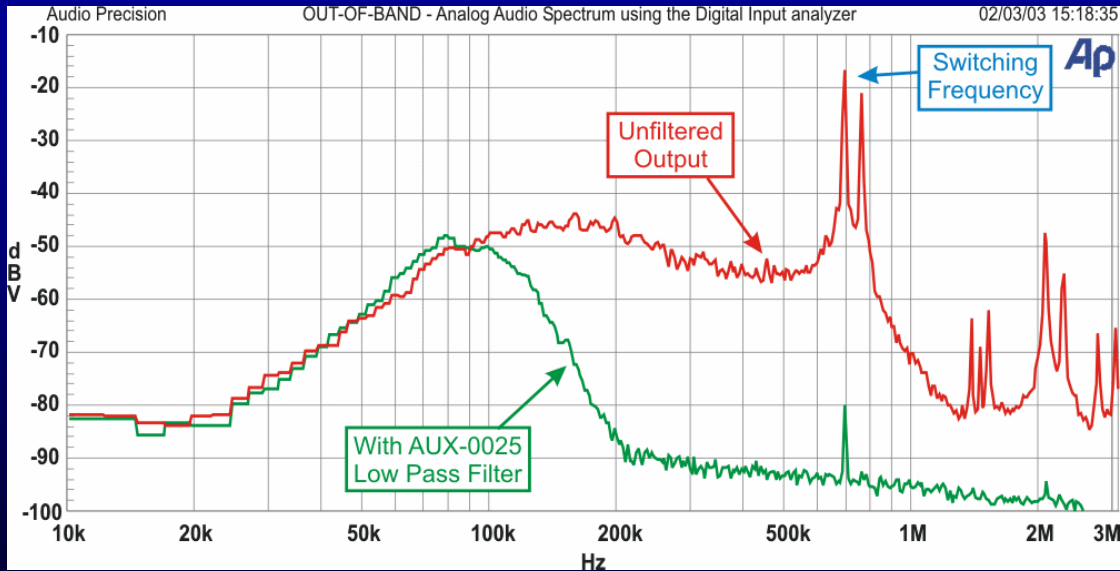


## **Signal After Filtering**

Artifacts are now clearly  
visible (and measurable)



# Typical Frequency Domain Effect



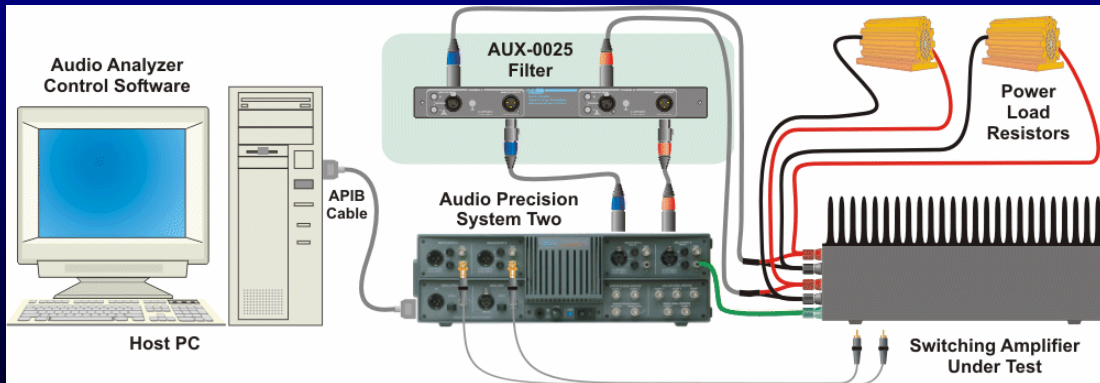
Red trace is unfiltered, green trace after filtering with AUX-0025

## *Some Useful Class-D Amplifier Tests*

- Noise and Hum
- Distortion (THD+N and IMD)
- Flatness (Response)
- Efficiency
- *See Whitepaper'' by B. Hofer (can be downloaded from [www.audioprecision.com](http://www.audioprecision.com))*

# *Measurement Setup with AUX-0025*

- Avoid ground connections through signal cable shields
- Do not locate AUX-0025 near strong magnetic fields



## *Measuring Noise and Hum*

- Weighted versus Unweighted measurements
- Sharp bandwidth limiting may be necessary to reject switching frequency artifacts
  - *“standard” weighting and bandwidth limiting filters in most audio analyzers have relatively soft 3-6 pole roll-off characteristics*
  - *AP recommends using both the AUX-0025 and the S-AES17 filter option*

# *S-AES17 Option Stop Band Attenuation*

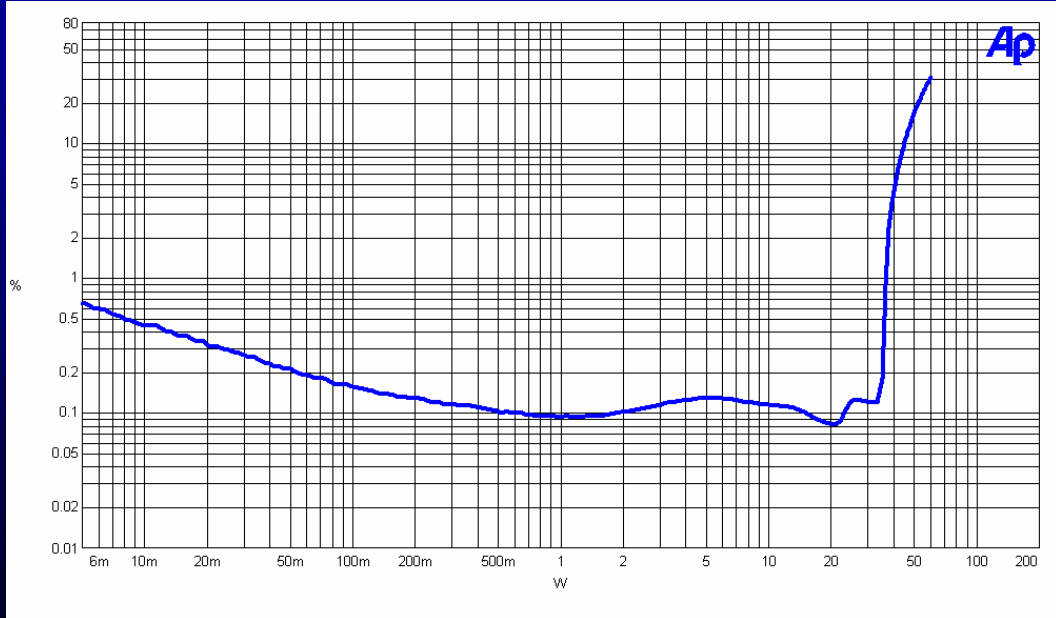
- 20 kHz mode: <-60 dB, 24 kHz–200 kHz
- 40 kHz mode: <-60 dB, 48 kHz–200 kHz



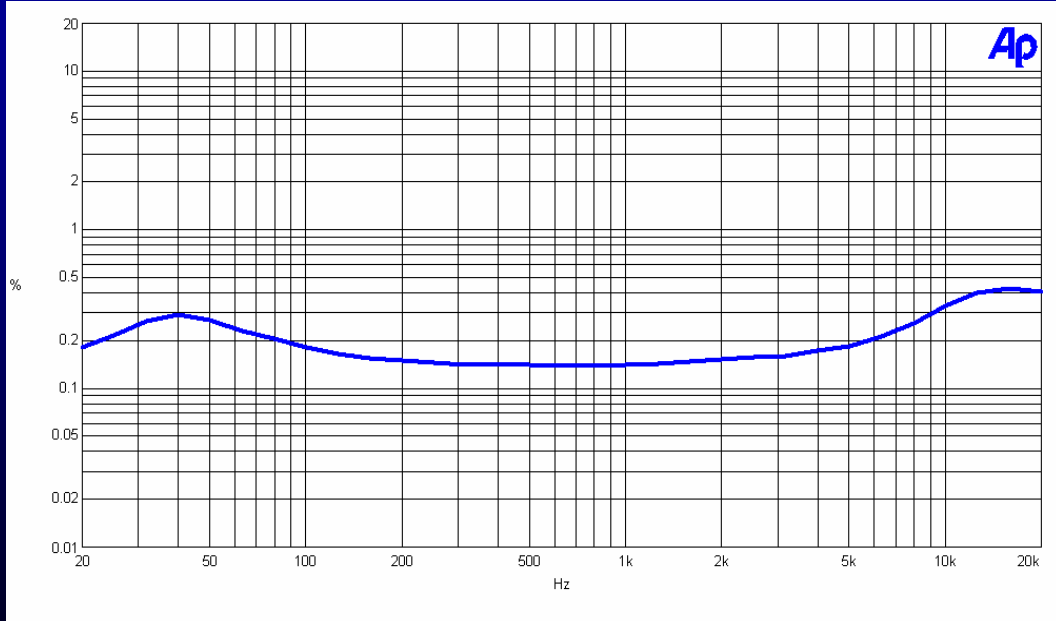
## *Measuring Distortion*

- 1 kHz THD+N versus Amplitude is a good basic test of amplifier performance
  - *it clearly reveals the maximum useable output*
  - *it also includes the effects of hum, noise, and ???*
- THD+N versus Frequency can reveal interesting, some unexpected circuit behavior
  - *carefully sweep through sub-harmonics of switching frequency to look for evidence of loop instability*
  - *also sweep through ac mains related harmonics to look for inadequate power supply rejection effects*

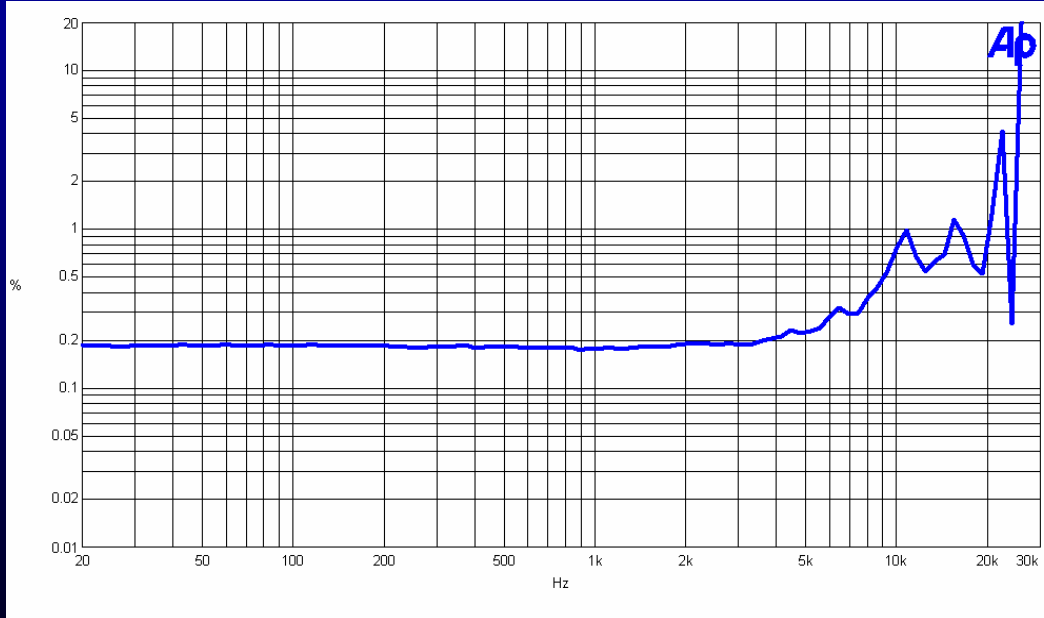
# *THD+N at 1 kHz versus Amplitude*



# *THD+N versus Frequency*



## *THD+N versus Frequency (example 2)*



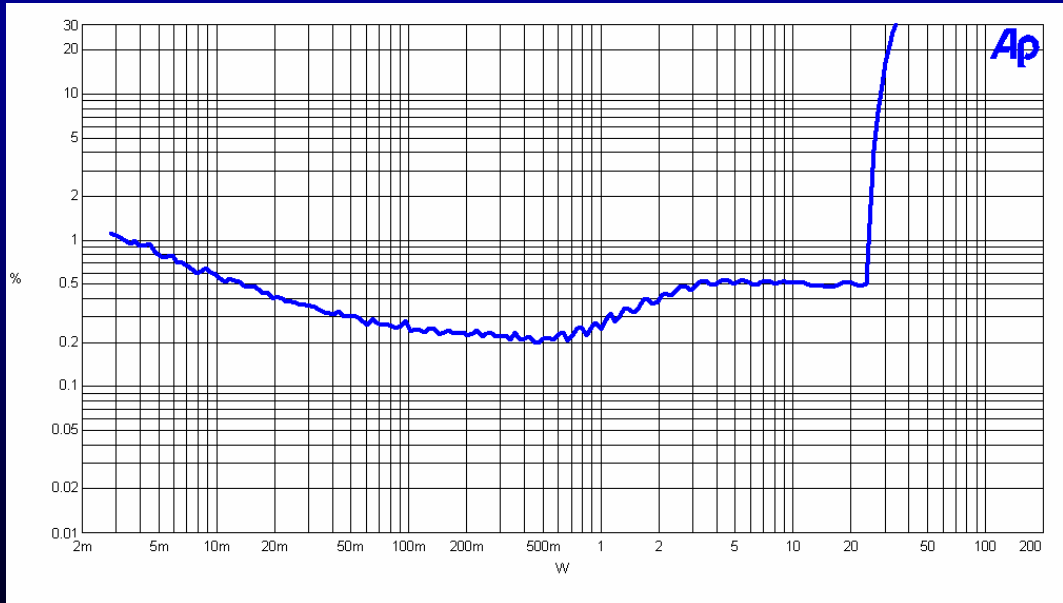
## *THD+N Limitations*

- THD+N is no good for investigating non-linearity in the upper half of the audio band
  - *harmonics fall outside of measured range*
  - *beat-frequency products that fold back into the audio band can be attenuated by the notch filter*
- THD+N is a bandwidth limited measurement. The nature and roll off rate of the bandwidth limiting can profoundly affect measurements.
  - *Audio Precision recommends use of the AES17 filter*

## *SMPTE (or DIN) IMD Testing*

- SMPTE IMD measures the degree of amplitude modulation of an HF tone in the presence of an LF tone (typically 60 Hz + 7 kHz, 4:1)
- SMPTE IMD is a very sensitive test of simple transfer function non-linearity
  - *a good measure of PWM linearity*
- SMPTE IMD should be swept versus amplitude
  - *often shows a similar characteristic to 1 kHz THD+N*

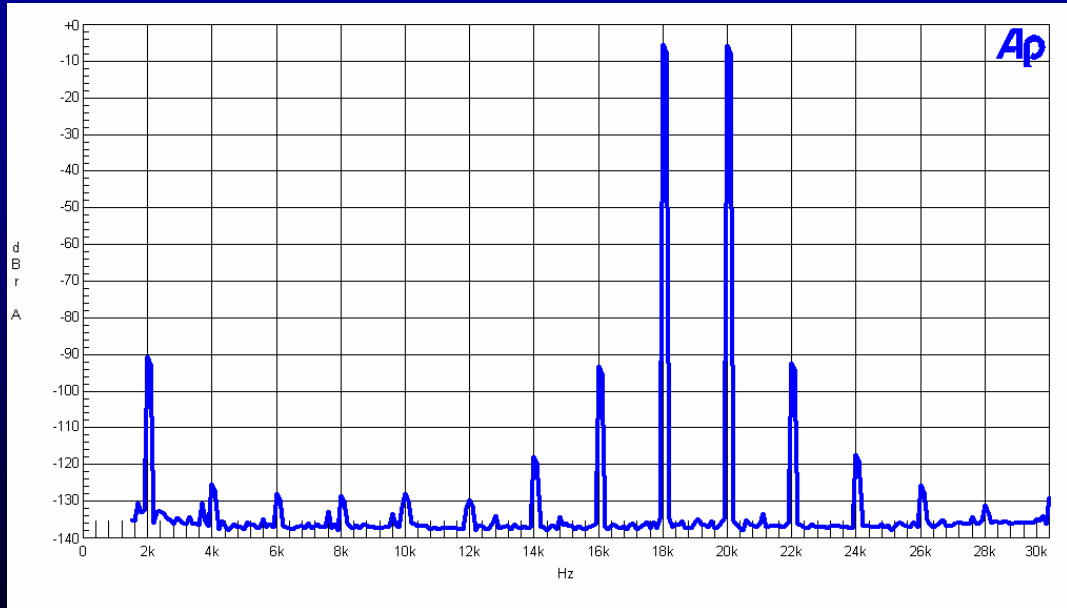
# Typical SMPTE IMD versus Amplitude



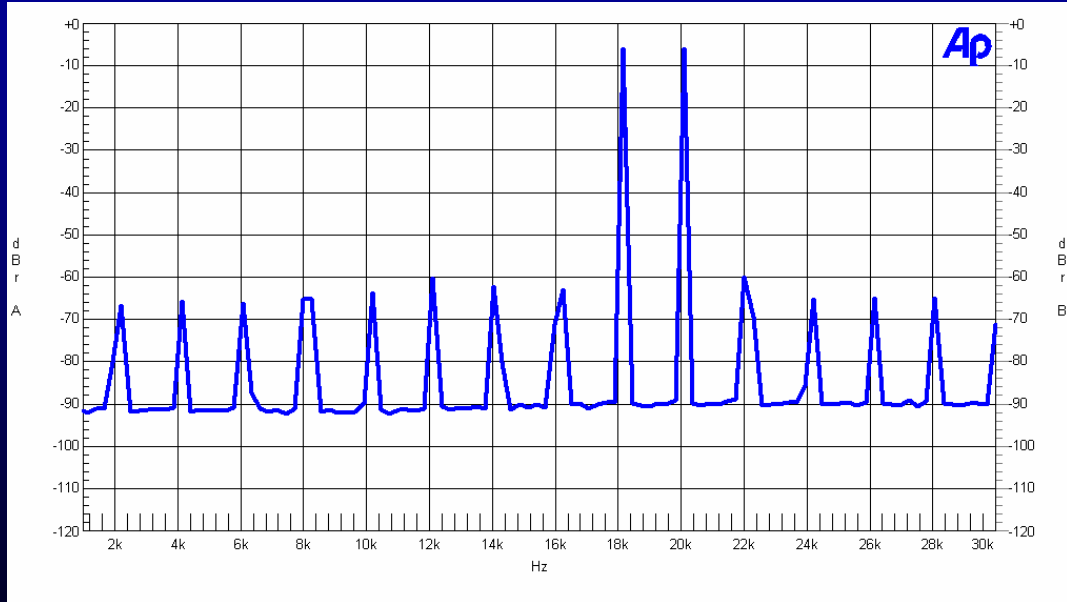
## *Twin Tone IMD Testing*

- Consider investigating Twin Tone IMD using two closely spaced frequencies near the upper edge of the audio pass band
- Audio Precision recommends a twin tone signal combination of 18 kHz and 20 kHz to really “separate the men from the boys” regarding higher performance amplifiers
  - *2nd order distortion will appear at 2 kHz*
  - *3rd order distortion will appear at 16 kHz and 22 kHz*

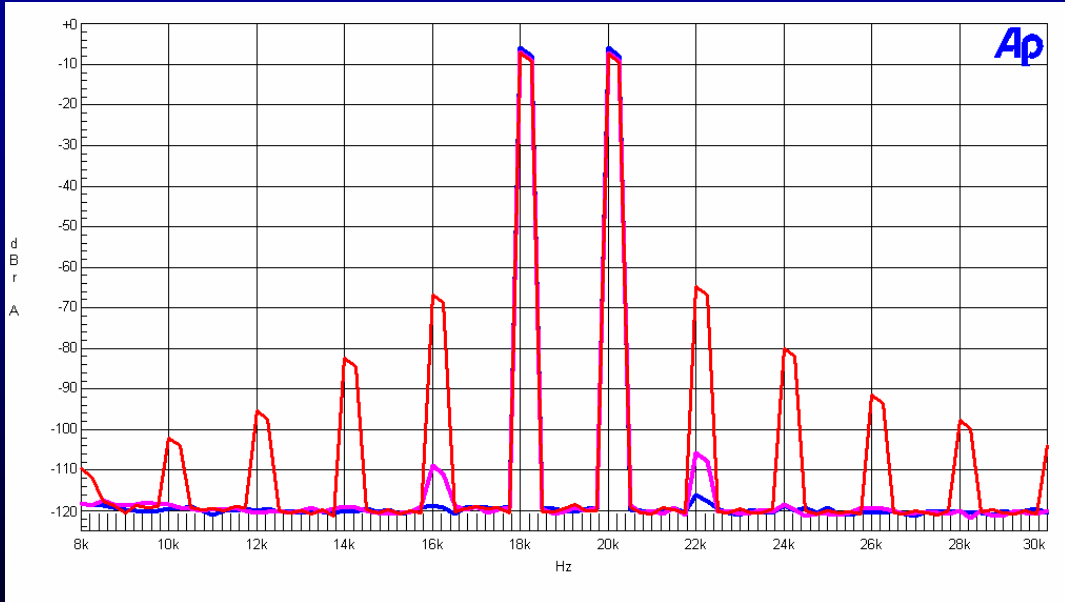
# *Twin Tone IMD of good linear amp...*



# *...versus a so-so Class-D amplifier*



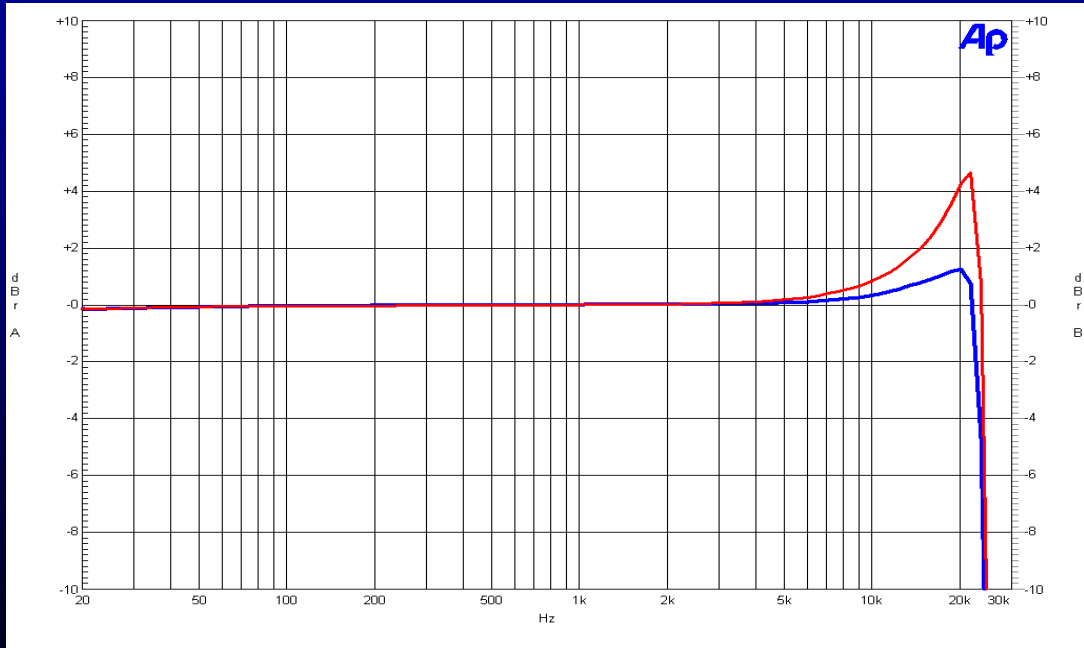
# *Filter Inductor Non-linearity*



## *Measuring Flatness (Response)*

- Always measure with rated test load (2-8 Ohm)
  - *Unloaded response can show significant peaking due to the resonance of the output LC filter*
- You may also want to check response at several different output levels
  - *The design of Class-D amplifiers is still evolving*
  - *Some may exhibit interesting changes in response versus output power level*

# *Effect of Test Load on Response*



## *Measuring Amplifier Efficiency*

- Typically done at 1 kHz with 8 Ohm load
- Input power must reach equilibrium, especially at relatively low power levels!
  - *Allow sufficient time for energy storage elements to stabilize when sweeping amplitude*
- Output power measurements can be corrected for the -0.05 dB insertion loss of the AUX-0025 filter
  - *Enter load resistance that is low by -0.1 dB (-1.2%)*

## *Summary*

- Testing Class-D amplifiers can be a challenging task due to the inherent nature of the output signal
- Audio Precision strongly recommends the use of its passive input filter accessory (the AUX-0025) to prevent inaccurate measurements
- Class-D amplifier performance is currently worse than the best of linear designs, but improving...

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