

*AES bijeenkomst
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heynen



Testing High Performance Audio A-D and D-A Converters



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Today's Audio D-A Converters

- Sigma-Delta, 48-200ks/sec
- Differential current output requiring analog output stage and low pass filter
- < -110 dB THD+N (20 kHz BW), but...
- Significant out-of-band energy

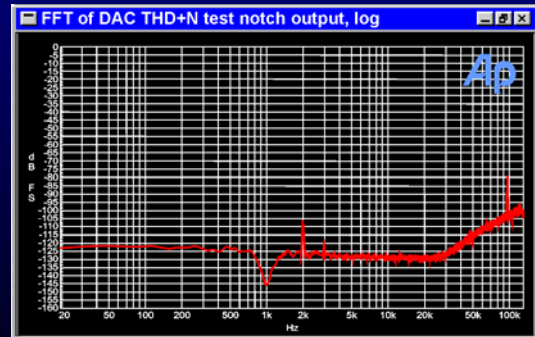
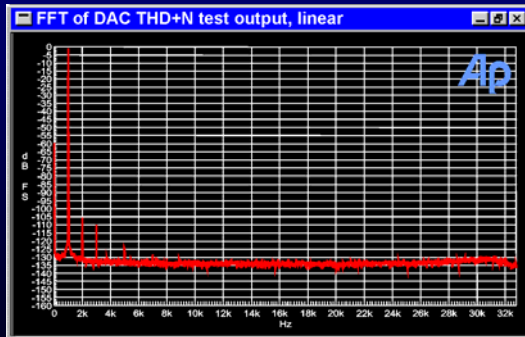
- *Residual THD+N is not likely to improve very much within current technology*

D-A Distortion Testing

- A very pure digital sine wave is applied to the input of the D-A while its analog output is analyzed
- FFT analysis
- THD+N versus Amplitude
 - *Best single measure of D-A performance*

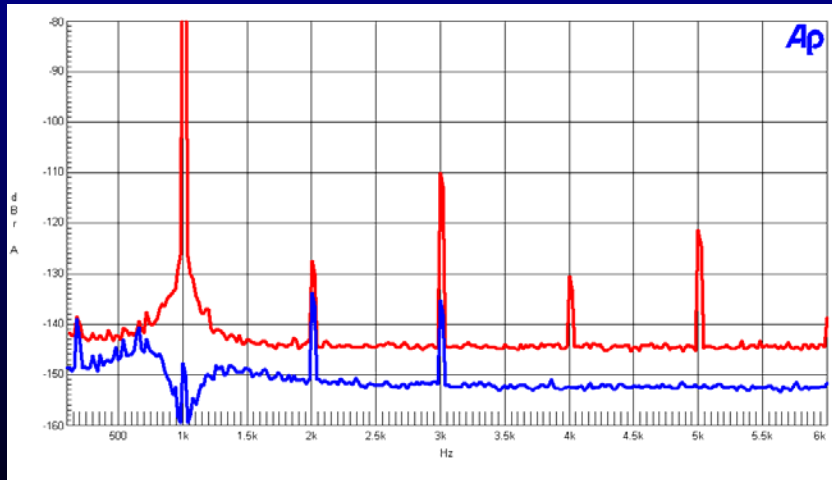
FFT Analysis

- FFT spectra reveal important details
- Linear and Log frequency axis displays each have their own advantages



Extending FFT Dynamic Range

- Use analog analyzer notch filter output as the FFT source to avoid A-D residual contributions



Typical Distortion Profile

- When D-A output stage non-linearities are well balanced, distortion is dominantly odd order (symmetrical, polarity independent)
- Analog output filter can be a major source of even order (polarity dependent) distortion even if the converter outputs are perfect
 - *non-linear input capacitance of op-amps*

THD+N

- Intuitive, simple to measure
 - *a single notch filter with*
 - *a band-limiting filter (usually 20 to 20kHz)*
 - *followed by a RMS meter*
- Insensitive to high frequency non-linearity because harmonics are out of band

Bandwidth affects THD+N

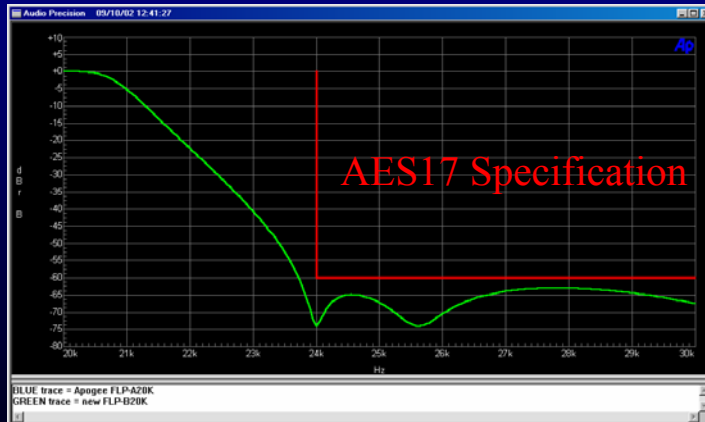
- The noise component of THD+N is inherently a function of measurement bandwidth and the shape of the bandwidth limiting characteristic
 - *Noise is proportional to the square root of the measurement bandwidth for “white” noise*
- The 3-6 pole filters in most audio analyzers are NOT sufficiently steep to reject the large out-of-band noise caused by sigma-delta conversion

The AES17 Filter Option

- AES17 specifies a very sharp bandwidth limiting filter when measuring THD+N in signals that have significant energy content above the audio band
 - *20 kHz bandwidth is most common*
 - *40 kHz with certain 96k converters*
 - *80+ kHz requested - ???*
- Achieving the AES17 specifications requires an elliptic low-pass filter of at least 7th order

AES17 Option Stop-Band

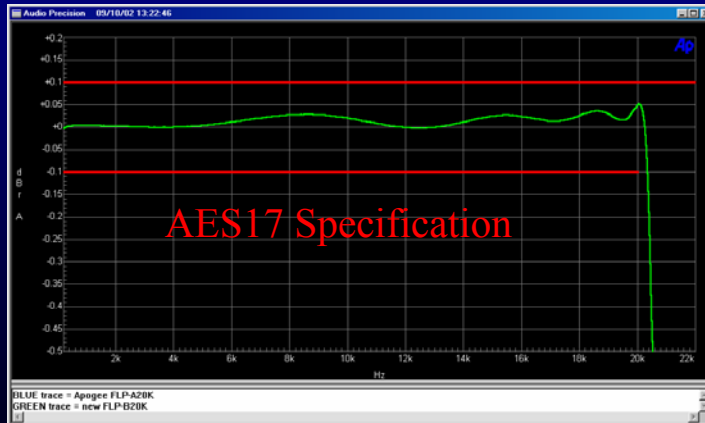
- Specifications
 - 20 kHz mode: <-60 dB, 24 kHz–200 kHz
 - 40 kHz mode: <-60 dB, 48 kHz–200 kHz



AES17 Option Response

- Specifications

- 20 kHz mode: ± 0.10 dB, 10 Hz–20 kHz
- 40 kHz mode: ± 0.10 dB, 10 Hz–40 kHz

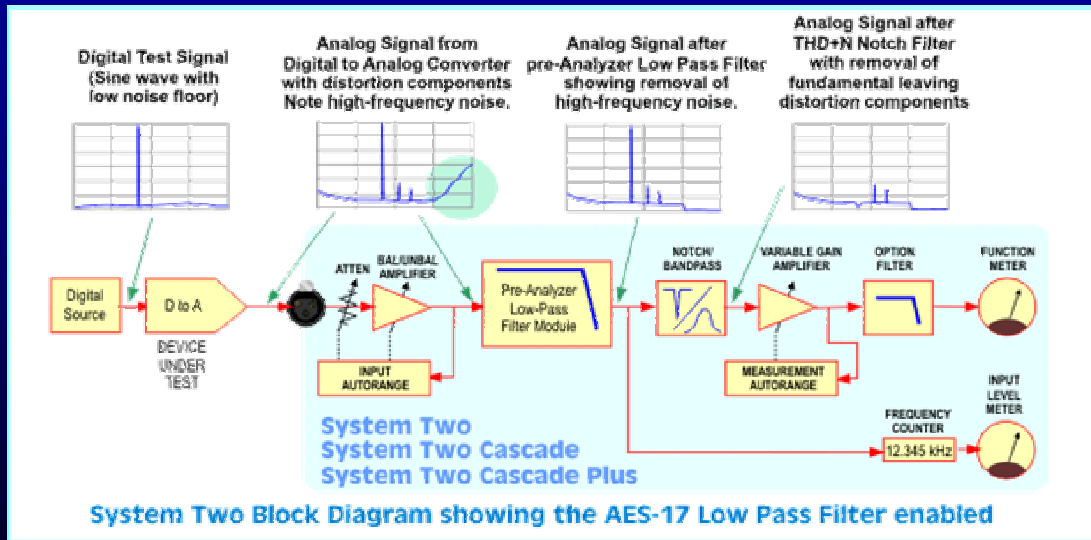


Comparison of Old versus New

- The older AES-17 filter employed a single stage architecture that significantly degraded residual THD+N
- New S-AES17 option (dual filter architecture) offers substantial improvement



AES17 Option Block Diagram



Decibels, Full Scale, & 0 dB FS

- AES-17 defines Decibels Full Scale (dB FS)

$$\text{Signal in "dB FS"} = 20 \cdot \log(A/B)$$

where:

A is the RMS amplitude of the signal

B is the RMS amplitude of a sine wave that has the maximum positive peak value permitted

- Thus a “Full Scale” sine wave has an amplitude of precisely 0.000 dB FS

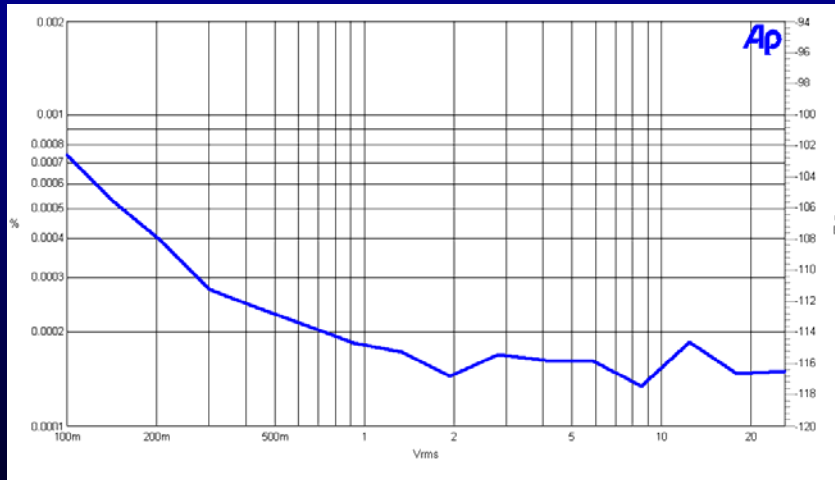
Graphing Recommendation

- Since converters have different scale factors (the ac output level with a full scale digital input), AP recommends THD+N graphs be displayed in units of “dB FS” or “dBr” (where 0 dBr = full scale)
- Allows meaningful comparison between different converters

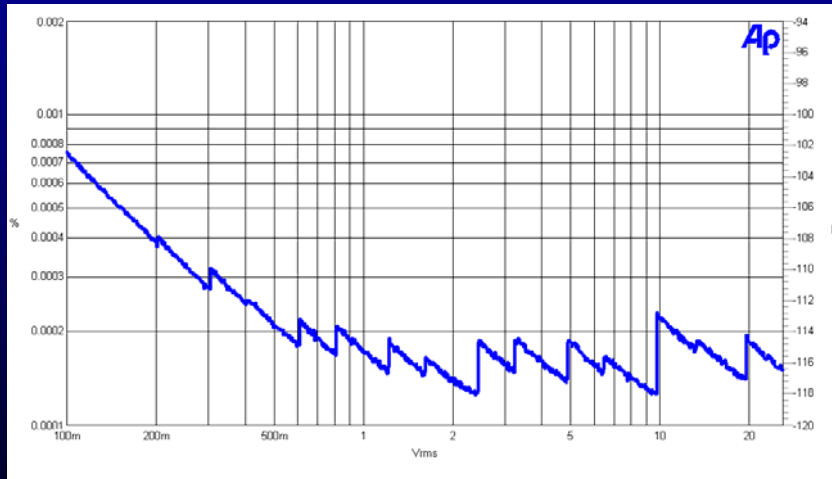
Optimum Full Scale Voltages

- 2-2.25 V_{rms} and 8-8.5 V_{rms} for 0 dB FS will give optimum results using the Audio Precision Cascade and 2700 families of analyzers
- Other analyzers will likely have their own unique “sweet spots”

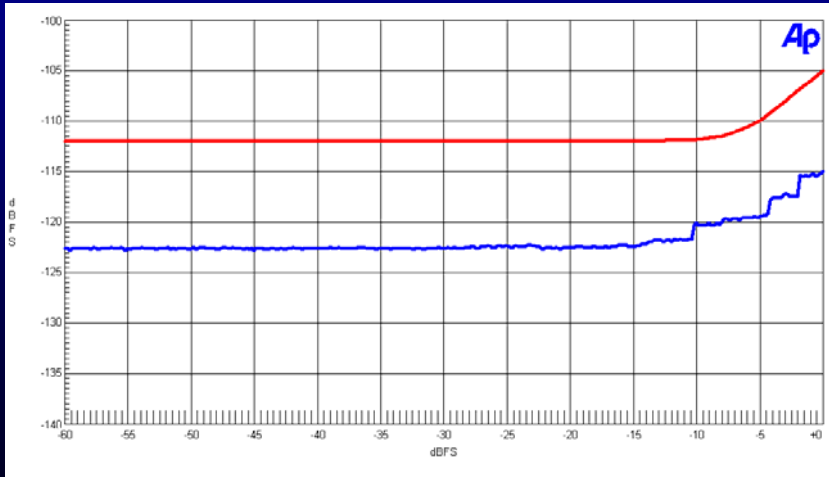
System THD+N, 15 steps



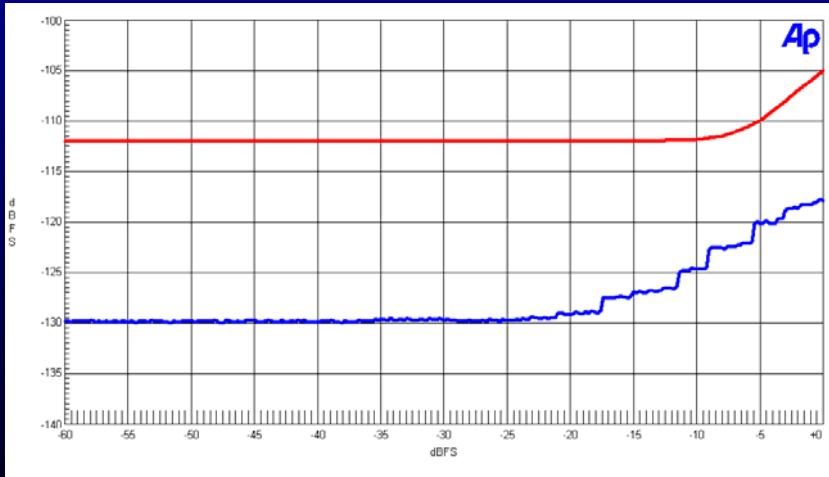
System THD+N, 1000 steps



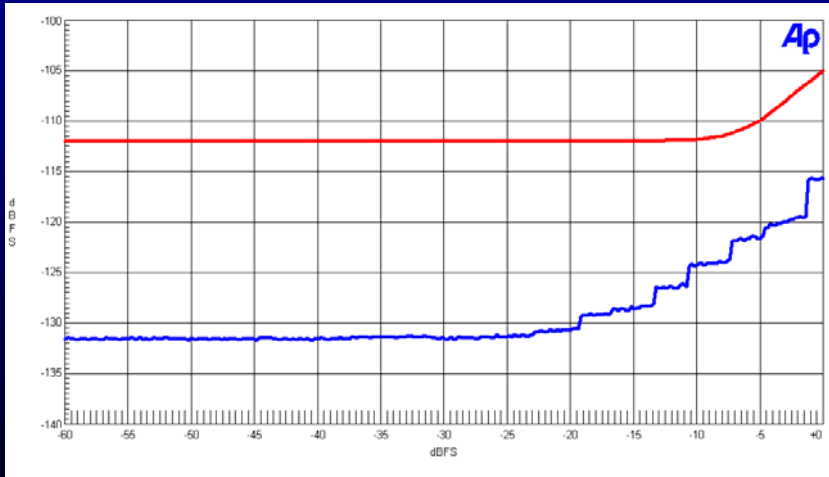
Residual THD+N, 0 dB = 1.0 V



Residual THD+N, 0 dB = 2.3 V



Residual THD+N, 0 dB = 2.8 V

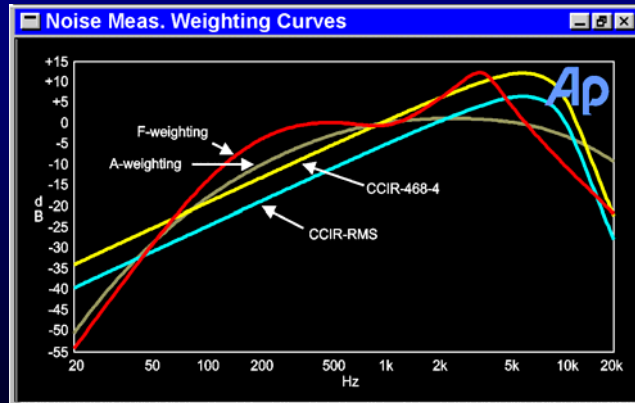


D-A Noise Measurements

- To avoid the shortcomings of the idle channel noise measurement, the conventional measurement of D-A noise is to measure the noise in the presence of a signal
- The signal is a properly dithered 997 Hz tone at -60 dB FS which is then removed from the D-A output with a notch filter. The remaining signal is low-pass filtered to limit the bandwidth and the amplitude is measured and expressed in terms of “dB FS” or “dBr”.

Noise Weighting Filters

- Weighting filters are invoked to make noise measurements correlate better with audibility



Noise Measurement Comparison

(valid only with white noise)

20 kHz ideal, rms	0.00 dB
A-weighted, rms	-2.33 dB
CCIR 468-4 unwtd, rms	-0.07 dB
CCIR-RMS (2kHz ref)	1.39 dB
CCIR 468-4 wtd, rms	7.01 dB
CCIR 468-4 wtd, q-pk	11.60 dB

Calibrating FFTs for Noise

- The Y-axis can be scaled to read dB FS for 1 Hz bandwidth (Noise / root-Hz)
- This spectral density measure is useful for noise analysis
- The correction to convert the scale depends on the FFT window and the bin width

FFT Window Noise Factors

(valid only with white noise)

None	1.000	0.00 dB
Hann	1.225	1.76 dB
BH-4	1.416	3.02 dB
Rife-Vincent 5	1.621	4.19 dB
AP Equi-Ripple	1.622	4.20 dB
Flat-Top	1.955	5.82 dB

Today's Audio A-D Converters

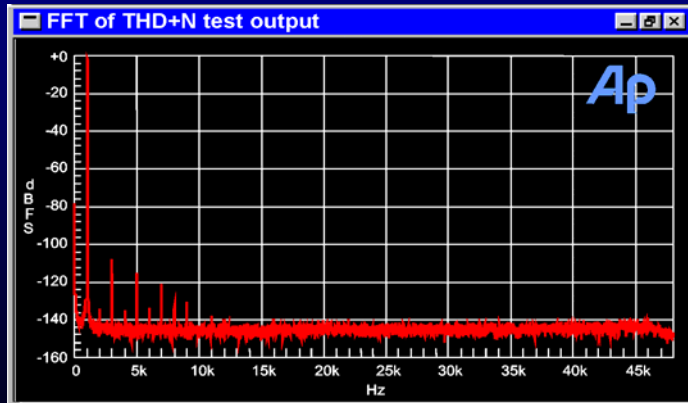
- Sigma-Delta, 48-200ks/sec
- Differential analog input
- <0.003 dB flatness, 20-20 kHz
- <-110 dB THD+N at 1 kHz (or better!)
- *Significant performance improvements not foreseen by any major A-D manufacturer*

A-D Distortion Testing

- FFT analysis
- THD+N analysis
 - *Best single measure of A-D performance*
 - *A very pure analog signal source is applied to the input of the A-D while its digital output is analyzed*

Typical Distortion Spectrum

- Sigma-Delta A-D converter distortion is often dominated by odd order components



Odd Order Distortion

- Caused by symmetrical non-linearity
 - *interaction of the A-D non-linear input impedance with non-zero source impedance*
 - *junction capacitance variation vs voltage*
- Increases with increasing sample rate
 - *best performance almost always at 48ks/sec*

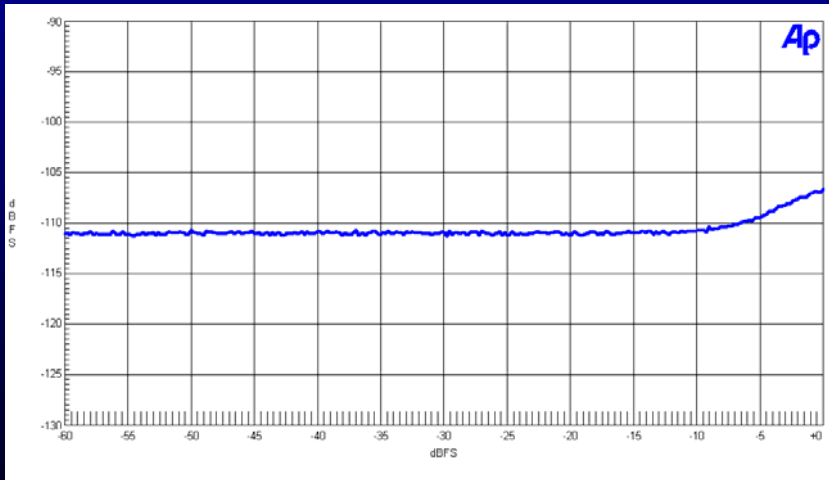
Even Order Distortion (2HD)

- Caused by asymmetrical non-linearity
 - *super-imposed input common mode signal*
- Low frequency effects can be corrected or nulled by introducing a slight ratio error into the differential drive circuit

Sample Rate (SR) Effects

- 3 HD usually increases with SR
 - *interaction of input impedance and non-zero source impedance*
- Gain (scaling) usually decreases with increasing SR
 - *effective input impedance decreases due to “flying cap” input circuit design*

Typical A-D Residual THD+N (at 1 kHz with 20 kHz measurement BW)



Graphing Recommendation

- Since different converters have different scale factors (the ac level required to obtain a full scale digital output), AP recommends displaying THD+N graphs in amplitude units of “dB FS” or dBr
- 0 dBr = analog level producing 0 dB FS digital output from converter

A-D Residuals vs 0 dBFS Level

- In general, the residual limitations of the test equipment when testing D-As is not as significant when testing A-Ds
- Analog generator residual noise is typically much lower than analyzer residual noise due to low impedance attenuators

Summary

- The performance level of audio converters is approaching the measurement limitations of the very best test equipment available
- A careful understanding of test equipment operation and ranging behavior can lead to better measurement results

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