



- ☐ 2700 Series
- ☒ APx555
- ☐ APx585 family
- ☐ APx525 family
- ☐ APx515

MEASURING A-TO-D AND D-TO-A CONVERTERS WITH APx555

by Steve Peterson

Introduction

This Technote explains how to use the APx555 high performance audio analyzer to measure Analog-to-Digital Converters (A-to-D or ADC) and Digital-to-Analog Converters (D-to-A or DAC). The measurements include those defined in AES17-1998 (r.2009) "AES standard method for digital audio engineering—Measurement of digital audio equipment" published by the Audio Engineering Society, and typical measurements specified in data sheets for converter products and converter IC components.

APx software version 4.1.1 project files provided with this technote automate the testing process and produce performance reports. The projects are designed to take maximum advantage of the high performance analog and digital features of the APx555 audio analyzer, including two high performance 1 MHz analog inputs. Download the Technote 124 zip file from the Audio Precision web site, unzip the project files, and load them with the APx 4.1.1 software (or later version).

APx555 Performance Features for Converter Measurements

The APx555 audio analyzer provides high performance analog features not available in other APx series analyzers or 2700 series analyzers. The essential difference is the low distortion and noise of the analog generator and analyzer, and high bandwidth FFTs. This level of analog performance makes it possible to test modern, high-performance converters.

High Performance Sine Generator

The APx555 high performance sine generator (HPSG) outperforms traditional DAC-based instrument designs by using a highly stable analog RC oscillator with extremely low residual distortion and noise. This low-distortion generator

performance is required to test high performance A-to-D converters. Specified THD+N distortion is ≤ -117 dB at 1 kHz, 2 Vrms (20 Hz–22 kHz measurement BW), though it typically measures < -120 dB. The generator frequency may be set from 5 Hz to 204 kHz, suitable for A-to-D stopband measurements at 192 kHz sample rates.

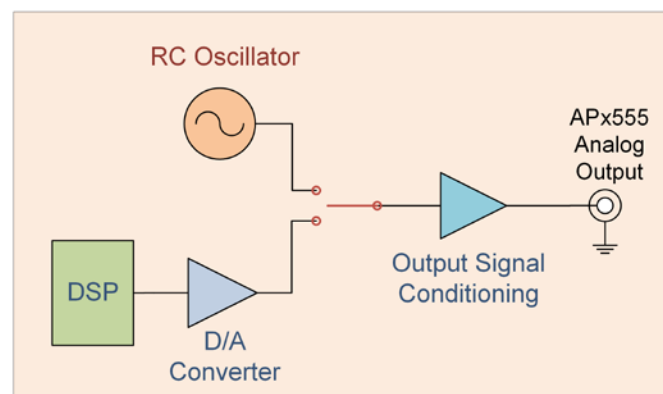


FIGURE 1. HPSG BLOCK DIAGRAM

A DSP-based D-to-A analog generator produces complex test signals from 1 mHz to 80 kHz for measurements other than THD+N: sine burst, dual sine (split frequency, variable phase, and DC offset), square waves, continuous sweep sine waves, IMD waveforms (SMPTE/DIN, DFD/CCIF, DIM), multitones, and arbitrary waveforms.

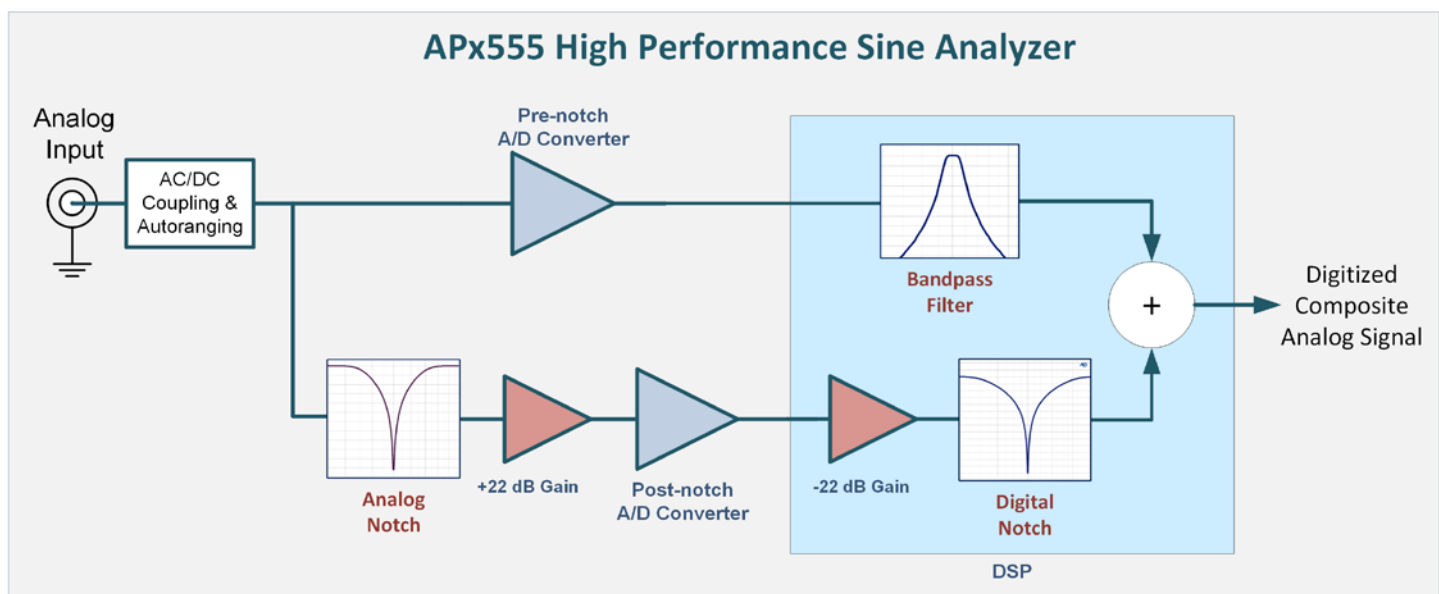


FIGURE 2. HPSA BLOCK DIAGRAM FOR EACH INPUT CHANNEL

High Performance Sine Analyzer

The corollary to the high performance analog generator is the analog high performance sine analyzer (HPSA) designed for THD+N, Dynamic Range, and FFT spectrum measurements of analog outputs, which is ideal for D-to-A converters.

The high performance sine analyzer utilizes two A-to-D converters per channel. After input ranging, the signal for each channel is routed to a full range “pre-notch” converter and an independent low noise agile analog notch filter.

Output from the “pre-notch” converters pass through digital bandpass filters. This removes harmonics, noise, and spurious signals from the input.

The analog notch filters eliminate the fundamental sine wave signal and pass only the distortion residual and noise. Output from each analog notch filter is amplified and then sampled by the “post-notch” converters, then attenuated prior to filtering with a digital notch. This method takes advantage of the full resolution of the “post-notch” converter, resulting in significantly improved measurement dynamic range and extremely low distortion.

The filters (digital bandpass, analog notch, and digital notch) can be tuned to the frequency of the input signal,

the frequency of the analog or digital generator, or to a user-defined frequency. APx555 input channels can be tuned independently to different frequencies.

Finally, the two signals in each channel (pre-notch and post-notch) are summed to produce a digital composite signal that contains the original fundamental sine wave and the distortion components. This composite signal is then available for subsequent measurement processing and display, including FFT spectra.

The composite signal is processed with another digital notch and filters to produce the THD+N Level (V_{rms}) measurement. The THD+N ratio measurement is computed from this THD+N level measurement and an RMS Level measurement of the composite signal. Additional measurements such as THD, Distortion Product Ratios, and the Noise component (minus harmonics) are computed from the composite signal as well.

The high performance sine analyzer operates at frequencies up to 1 MHz with two channels. These high-bandwidth capabilities are suitable to test out-of-band signals of D-to-A converters and to measure spectra of spurious signals above 5 times f_s at 192 kHz sample rates.

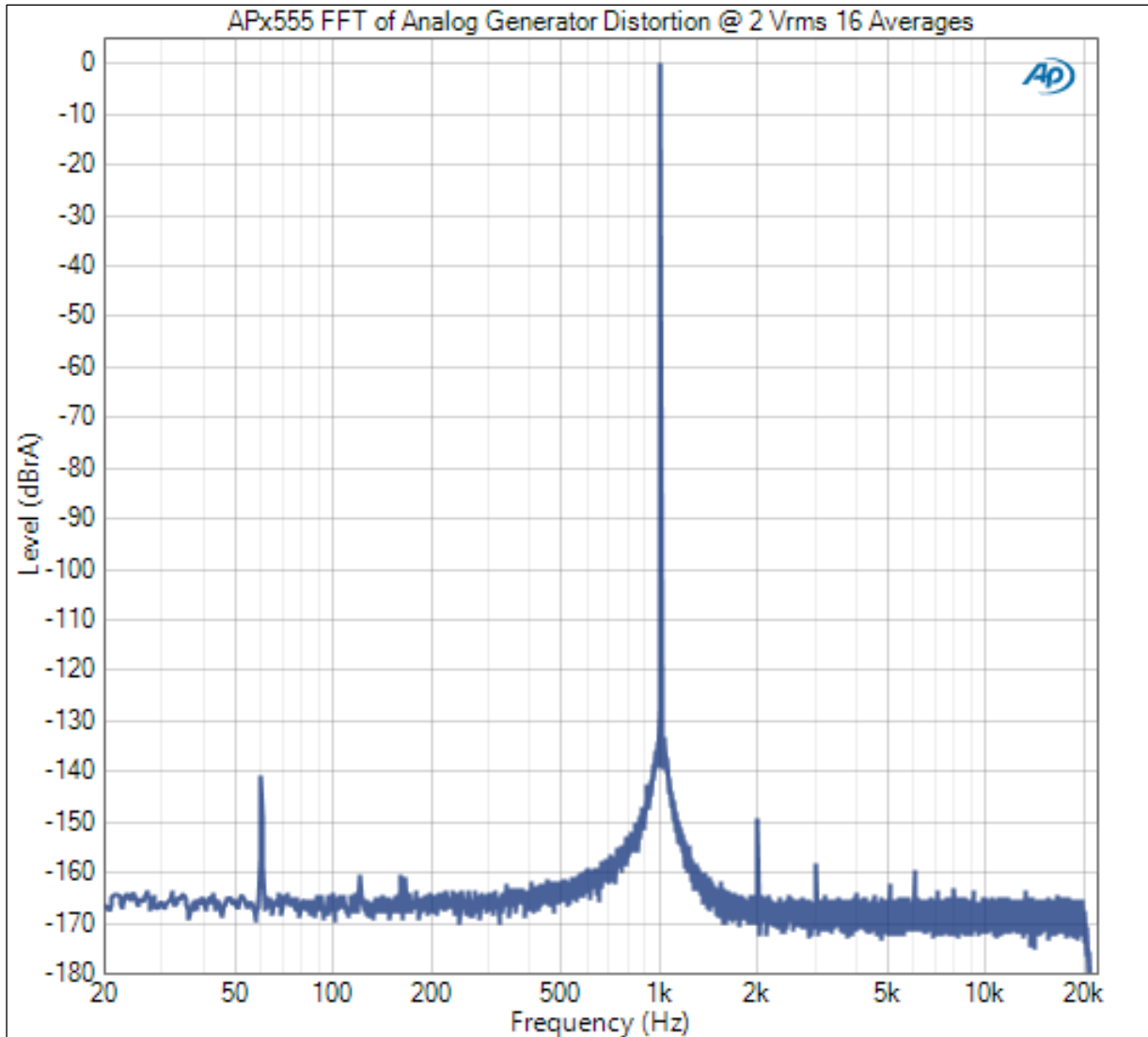


FIGURE 3. TYPICAL HPSG TO HPSA FFT, ANALOG LOOPBACK

The HPSA's THD+N measurement performance is ≤ -117 dB (22 kHz BW), typically < -120 dB at 1 kHz. Residual noise is ≤ 1 μ Vrms (22 kHz BW), typically < 6.2 nV/ $\sqrt{\text{Hz}}$ at 1 kHz.

Spectrum displays reveal the remarkable dynamic range of the full scale signal produced by the high-performance sine analyzer. The FFT spectrum in Figure 3 shows the typical performance of the APx555 in analog loopback mode using the high performance sine generator and high-performance sine analyzer together. Typical APx555 Dynamic Noise (DNR) is 125 dB with an analog loopback of -60 dBr (relative to 2 Vrms) input signal, a CCIR-2k weighting filter, at a measurement bandwidth of 20 kHz.

The APx555 analyzer can emulate the behavior of other APx analyzers when the HPSA is turned off. The APx software automatically switches HPSA off when it converts APx projects developed with other APx analyzer models, such as an APx525 with option BW52 (high-bandwidth analyzer option). This assures backward compatibility and reuse of APx projects.

Advanced Digital Input Output (ADIO)

The APx555 standard digital audio interface is the Advanced Digital Input Output module (ADIO). The ADIO interface provides digital audio interfaces to balanced AES-EBU (AES3/IEC60958-4), unbalanced S/PDIF (IEC60958-3), and Optical I/O (EIAJ optical) on the device under test.



FIGURE 4. ADIO PANEL

ADIO outputs may be impaired to test a D-to-A input susceptibility to digital pulse amplitude, rise-fall time, jitter, common mode noise (for AES/EBU balanced interfaces), meta-data (VUCP), and forced parity errors. The ADIO input may also be used to measure the pulse amplitude and jitter of the digital output from an A-to-D converter.

ADIO supports digital bit depths to 24 bits and sample rates to 216 kHz. This technote will concentrate on the ADIO interface to test commercially available converters.

Advanced Master Clock

APx555 includes the Advanced Master Clock (AMC), which provides jitter generation and measurement capabilities when used with jitter-enabled I/O modules.

AMC also provides AES11 Digital Audio Reference Signal (DARS) reference in and out, clock sync in and out, and trigger in and out on connectors on the rear panel module.

AMC clock outputs may be impaired with controlled jitter (amplitude and frequency) to test jitter tolerance of the device synchronized to their outputs. AMC is required for certain AES17 tests that specify test instrument sync and reference capability for jitter tolerance tests of converter devices with external synchronization inputs.

AMC is standard on the APx555 and is available as an option for any other modular APX analyzer model.



FIGURE 5. ADVANCED MASTER CLOCK, REAR PANEL

Digital Serial Input Output (DSIO)

As with other APx analyzers, APx555 supports the multi-channel DSIO option for serial interfacing directly to digital audio ICs on a circuit board, typically used in design verification applications. DSIO provides up to 16 channels of I²S and other data formats at bit depths up to 32 bits with 1 to 4 serial data lines, master clock, bit clock, word clock, and channel clock. Transmitter and receiver clocks may be configured as master or slave.

DSIO supports sample rates up to 432 kHz. Transmitter and receiver sample rates may be set independently. DSIO is jitter capable when installed on any APX analyzer equipped with the Advanced Master Clock. This is useful for measuring input bit clock jitter from a device connected to the DSIO receiver or for measuring jitter tolerance of a device by adding calibrated jitter to all clocks and data lines received from the DSIO transmitter.

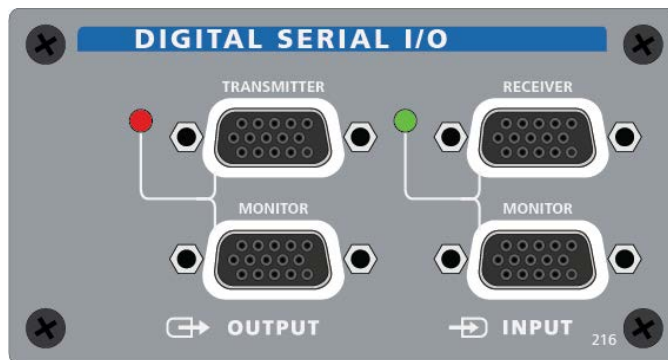


FIGURE 6. DSIO PANEL

The APx project files provided with this technote can be modified to use the DSIO interface as an alternative to the ADIO interface with very little change to the measurements.

APx Software Operating Modes

APx software version 4.1.1 provides two user-interface modes, Sequence Mode for automated measurement sequences, and Bench Mode.

Sequence Mode

Sequence Mode is the classic interface for APx users. It provides a sequence of signal paths, each containing measurements and measurement results.

Sequence execution performs each measurement and produces a formatted report containing test setup information plus graphic and tabular measurement result data. Sequence Mode is designed for test automation and is used extensively in the APx project files supplied with this technote.

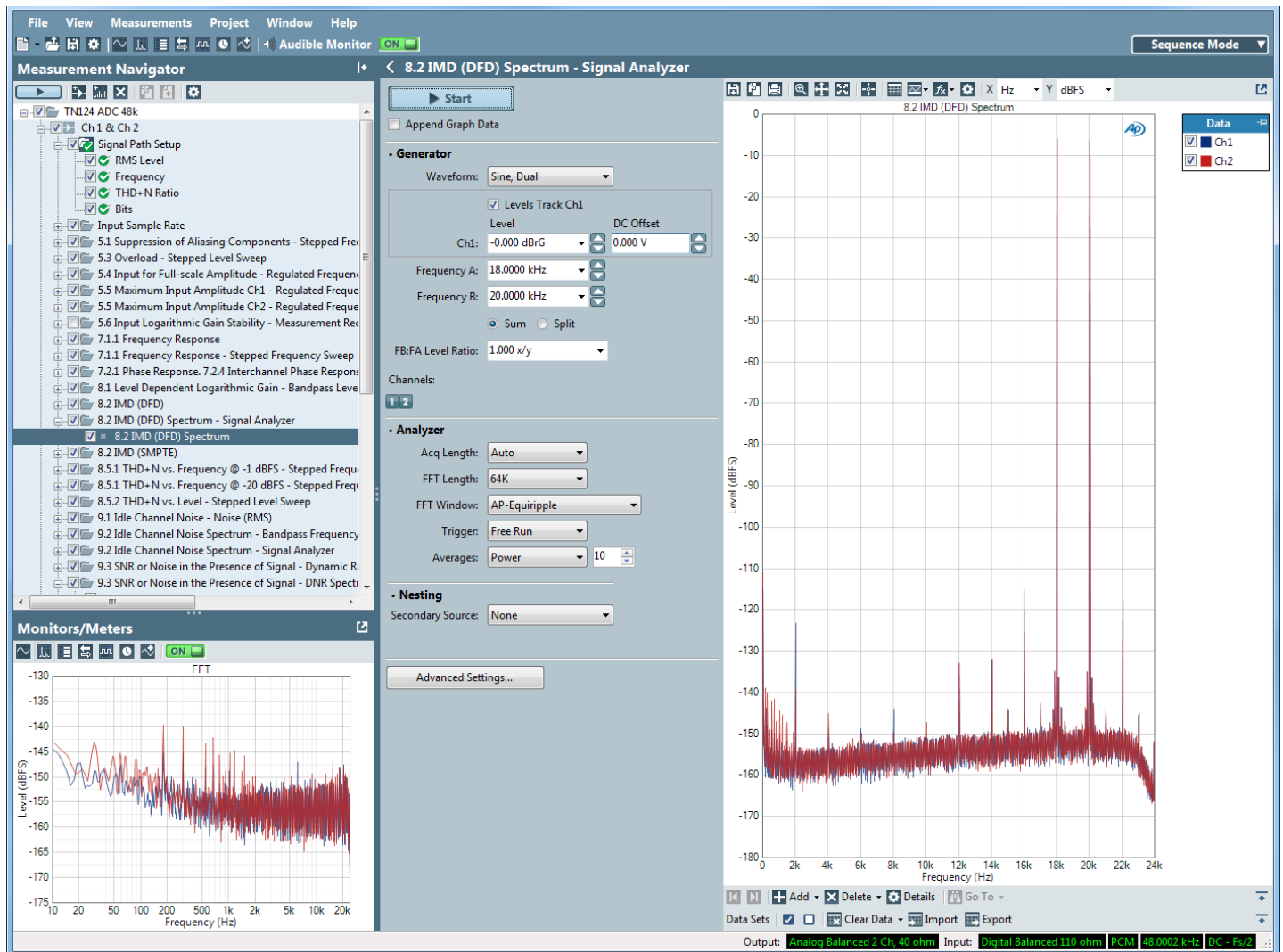


FIGURE 7. APx SEQUENCE MODE

Bench Mode

Bench Mode provides an interactive user interface preferable for design engineering and troubleshooting activities. Use Bench Mode to quickly explore the functionality of a converter prior to developing a sequence of measurements in Sequence Mode.

The flexibility of Bench Mode permits changing stimulus signals and measurement parameters while simultaneously seeing the results in live meters, waveform displays, and FFT spectrum displays. Nested sweeps simplify the process of measuring a family of curves, such as output THD+N distortion vs. Input Level vs. Input Frequency using swept sine waves.

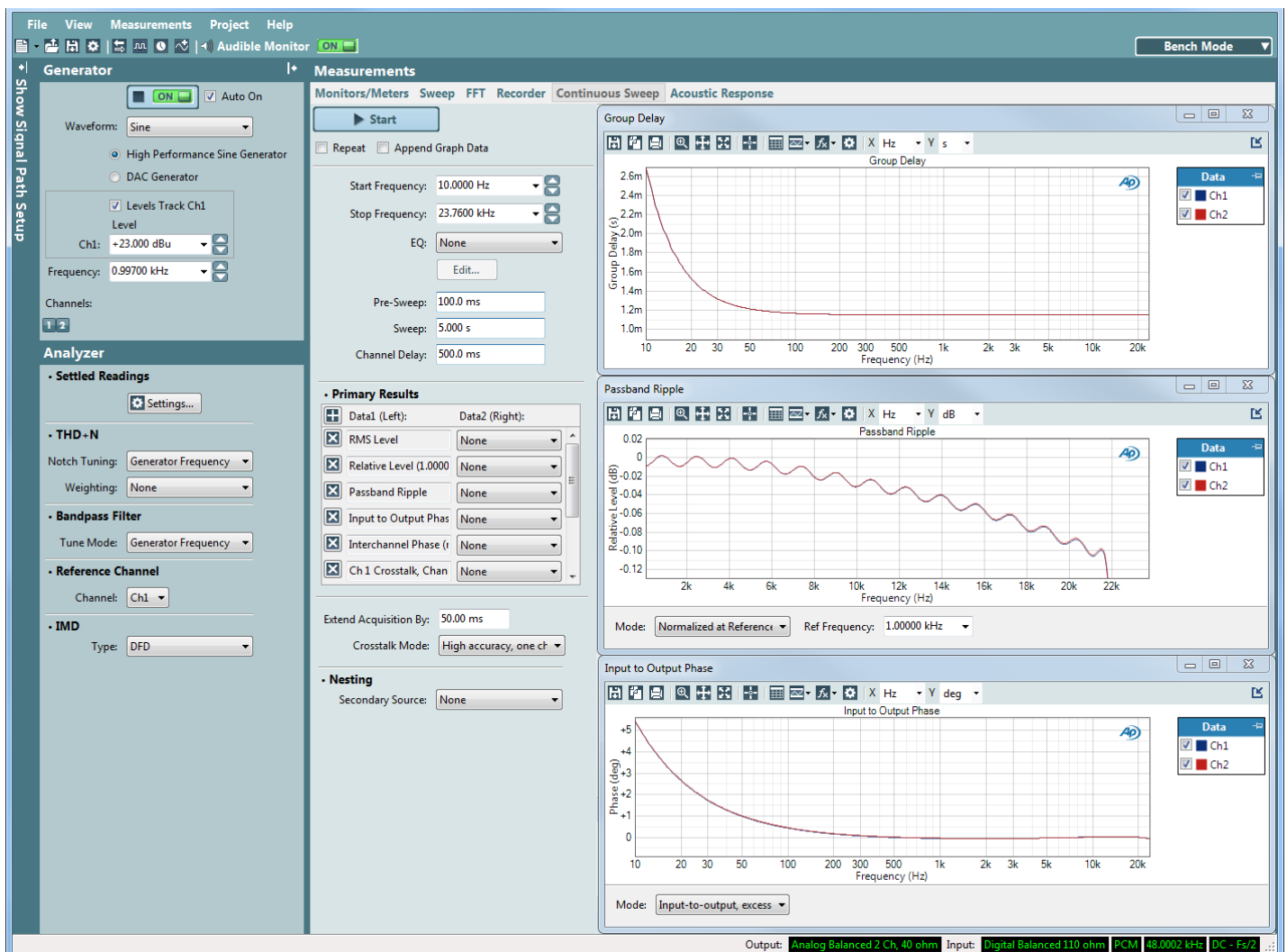


FIGURE 8. APx BENCH MODE

APx555 Measurements for Converter Testing

The 2700 series analyzer has been the industry standard converter test instrument for many years. APx555 provides many new hardware and software features and improved analog performance. Sequence Mode provides over 50 measurements that are suitable for many audio applications. The APx project files provided with this technote use a subset of these for high performance converter testing.

Bandpass Frequency Sweep

Bandpass Frequency Sweep is used for AES17 test 9.2 Idle Channel Noise Spectrum. The center frequency of a third-octave bandpass filter is swept at the output of the converter with no input signal applied. For a higher resolution alternative, use the Signal Analyzer to produce a detailed spectrum display. Both techniques are implemented in the project file.

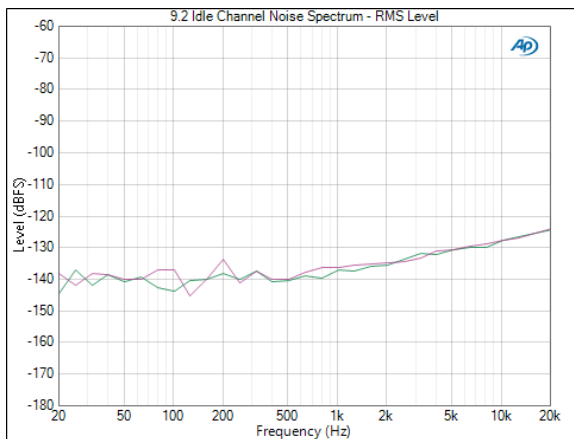


FIGURE 9. BANDPASS FREQUENCY SWEEP—ADC OUTPUT NOISE VERSUS FREQUENCY

Bandpass Level Sweep

Bandpass Level Sweep is used for AES17 test 8.1 Level Dependent Logarithmic Gain. This measurement sweeps the level of a 997 Hz sine wave input signal to the converter while measuring RMS level and gain at the output with a third-octave bandpass filter tuned to 997 Hz. The bandpass filter enables measurements below the wideband noise floor.

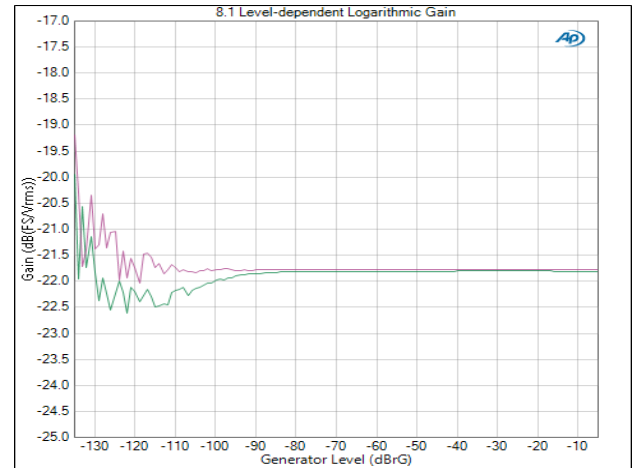


FIGURE 10. BANDPASS LEVEL SWEEP—ADC GAIN VERSUS INPUT LEVEL

CMRR IEC

CMRR IEC is used to test common mode rejection ratio often listed as a specification for commercial A-to-D converters with analog balanced XLR inputs.

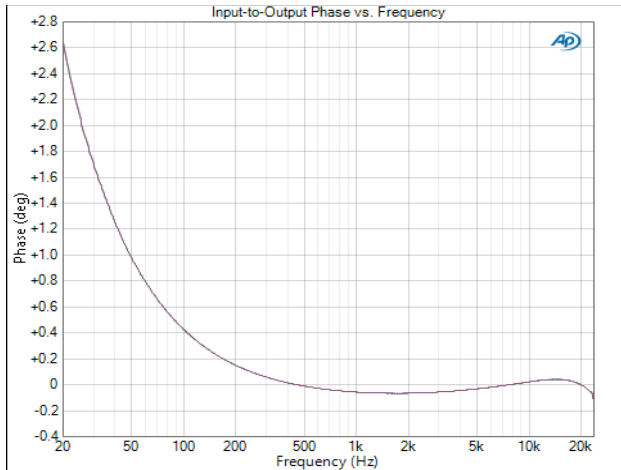
The APx555 implements the IEC60268-3 method of testing common mode rejection. The CMRR IEC measurement provides a single-value of the CMRR in each converter channel by the IEC technique, which unbalances the generator output circuit by first inserting a resistance in one leg (the Pin 2 measurement), and then the other leg (the Pin 3 measurement). The final CMRR IEC result is the worst-case of the pin 2 or pin 3 measurements.

Continuous Sweep

Continuous Sweep is used for AES17 tests 7.2.1 Phase Response, 7.2.2 Group Delay, 7.2.3 Interchannel Phase Response, 7.3 Delay, and 7.4 Polarity.

A continuous sweep is a brief log-swept sine wave (a Farina log chirp) that moves continuously across a specified range of frequencies. The converter output is acquired by the analyzer and is mathematically processed to provide a number of results.

Continuous Sweep can be used to sweep the entire passband of a converter up to 80 kHz in three seconds or less. The number of frequencies in the continuous sweep makes it suitable for high frequency resolution measurements of the passband of a converter and the low-magnitude ripple.



**FIGURE 11. CONTINUOUS SWEEP—
CONVERTER INPUT-TO-OUTPUT PHASE RESPONSE**

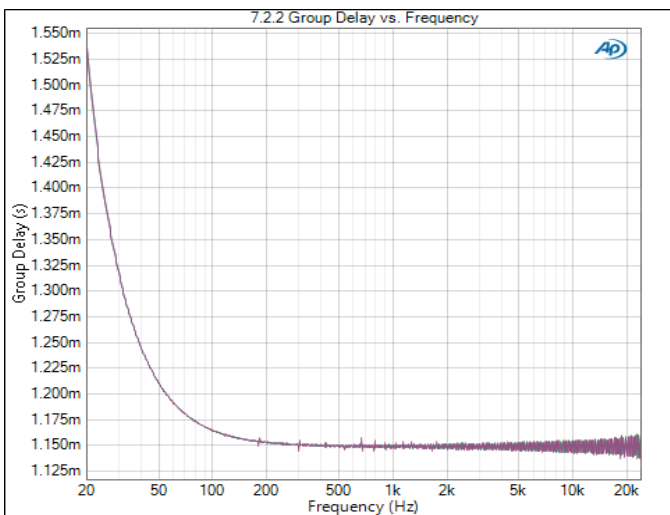
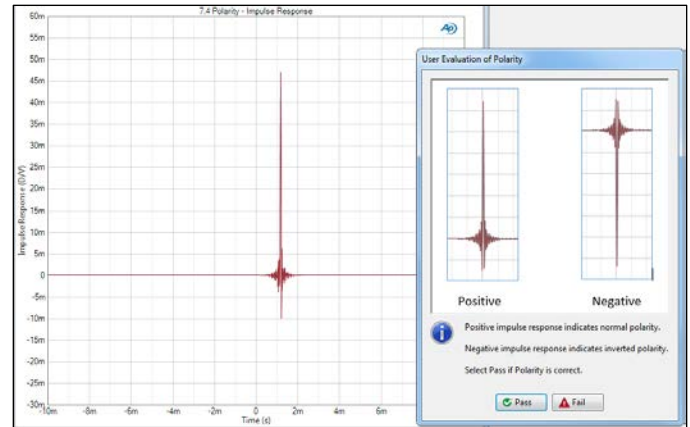


FIGURE 12. CONTINUOUS SWEEP—CONVERTER GROUP DELAY

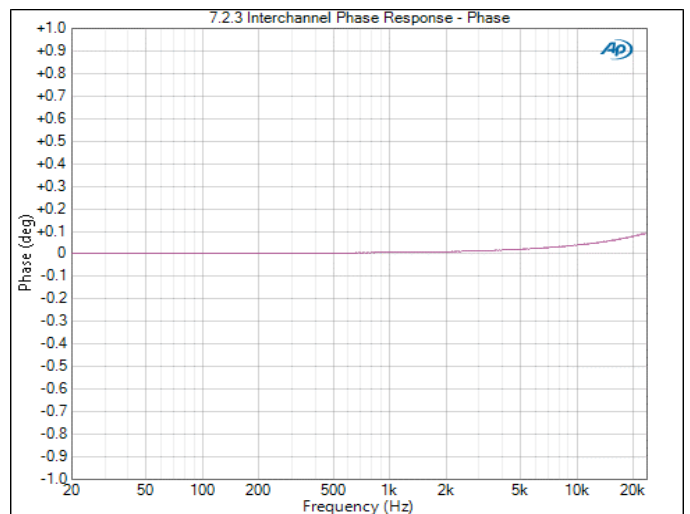
An overall measure of group delay can be computed from the group delay graph data with a Derived Result Standard Deviation function. The standard deviation of the graph data in Figure 12 above results in a group delay of 1.149 ± 0.007 ms.

The Impulse Response graph shows whether the impulse is positive or negative. A positive impulse response waveform indicates positive polarity.

Continuous Sweep is an excellent method to automatically measure converter input-to-output phase versus frequency, shown in Figure 11.



**FIGURE 13. CONTINUOUS SWEEP IMPULSE RESPONSE
INDICATES THE POLARITY OF THE CONVERTER**



**FIGURE 14. CONTINUOUS SWEEP—
CONVERTER INTERCHANNEL PHASE RESPONSE**

Crosstalk Sweep, One Channel Driven

Crosstalk Sweep, One Channel Driven is used for AES17 test 10.1 Crosstalk Sweep.

Crosstalk Sweep, One Channel Driven performs a series of stepped frequency sweeps where only one channel is driven at a time. Each sweep applies the stimulus signal to one channel only (initially, Channel 1). Each undriven channel is measured for crosstalk. Then the sweep is run again, with the next channel (Channel 2) driven. This cycle is repeated through the available output channels. The level measured at each frequency point in the undriven channel(s) is compared to the level measured in the driven channel. The ratio of the two is the crosstalk result for that channel.

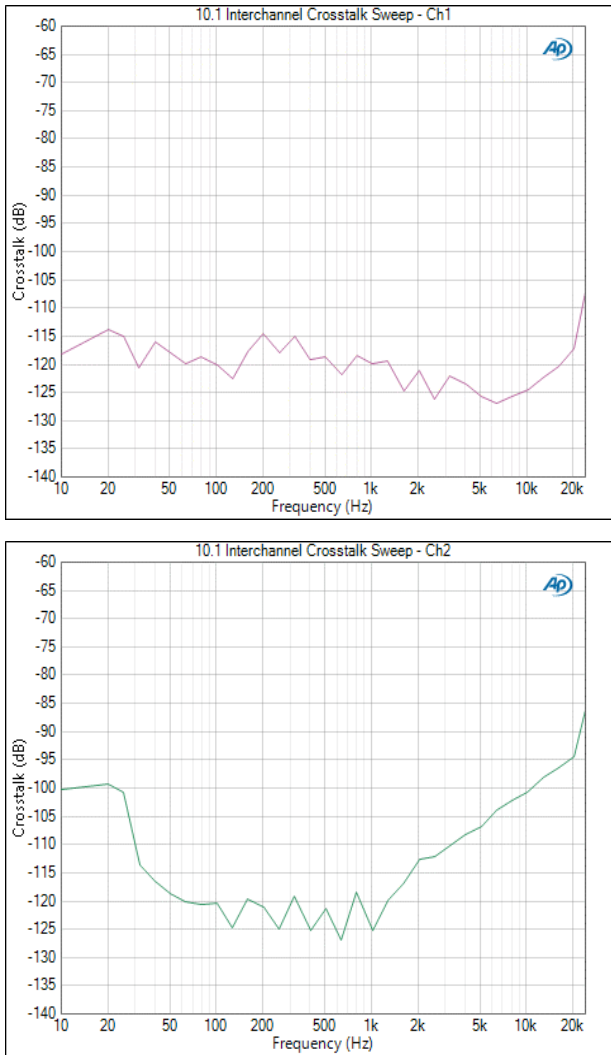


FIGURE 15. CROSSTALK SWEEP, ONE CHANNEL DRIVEN

Dynamic Range

Dynamic Range—AES17 is used for AES17 test 9.3 SNR or Noise in the Presence of Signal. Dynamic Range—AES17 is intended specifically for converter dynamic range and “noise in the presence of signal” measurements. A similar method (called dynamic range) is defined in IEC61606. The default settings for Dynamic Range—AES17 are those defined by AES17 9.3.

This method is used for two reasons:

1. In both ADCs and DACs, “idle tones” can be produced within the converter in the absence of applied signal. A low-level tone is applied to the converter to avoid production of idle channel noise. The low-level tone is removed by a notch filter before measurement.

2. In some DACs, the output of the device is switched off when there is no signal, providing an unrealistically quiet measurement. The low-level tone defeats this muting mechanism.

A Dynamic Range measurement of 115 dB or better is typical for a high performance 24 bit ADC at 48 kHz sample rate.

Frequency Response

Frequency Response is used for AES17 test 7.1.1

Frequency Response and databook tests for Passband Ripple and Frequency Response. The APx Frequency Response measurement uses the continuous sweep method to measure the response of each channel, plotted against frequency up to 80 kHz. A single value deviation result is also computed from the continuous sweep acquisition.

The continuous sweep method is inherently frequency selective and will not measure alias products above the folding frequency as the stimulus frequency approaches the folding frequency. The conventional technique using a stepped frequency sine wave and RMS level meter will not reject alias products near the folding frequency. The level meter will sum the alias signals with the test signal because they are very close together in frequency near the folding frequency, resulting in a higher response measurement. For example, a stimulus signal 100 Hz below the folding frequency would be summed with an alias signal 100 Hz above the folding frequency using a stepped frequency sweep. A continuous sweep technique avoids this and measures only the stimulus frequency component.

Converters operating at folding frequencies above 80 kHz must be tested with a stepped frequency sweep that can operate at up to 204 kHz.

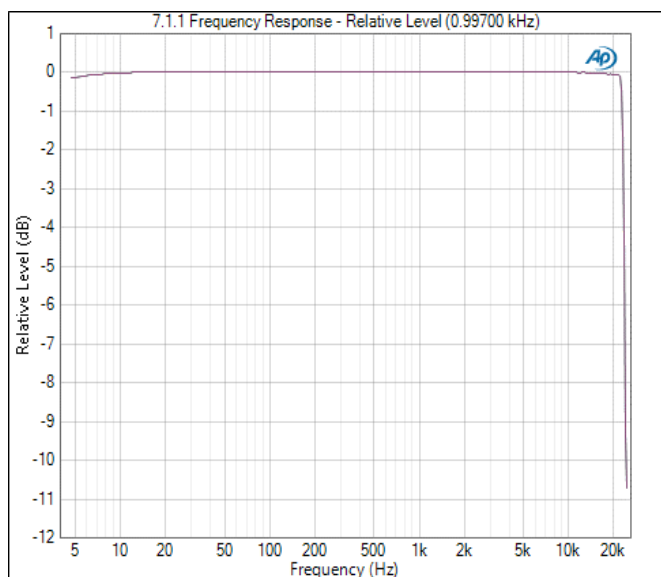


FIGURE 16. FREQUENCY RESPONSE—AES17 TEST 7.1.1

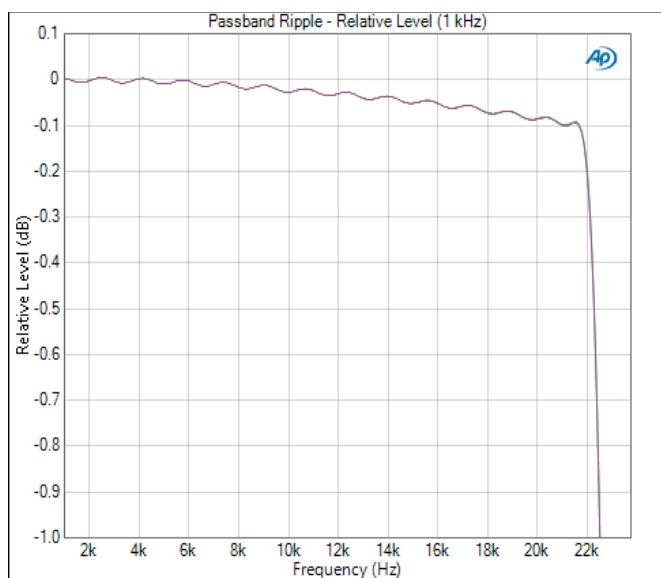


FIGURE 17. FREQUENCY RESPONSE—CONVERTER PASSBAND RIPPLE

IMD (DFD) and IMD (SMPTE)

IMD (DFD) and IMD (SMPTE) are used for AES17 test 8.2 IMD.

IMD (intermodulation distortion) measurements use two tones summed into a stimulus signal. This measurement provides single-value IMD ratio and IMD distortion product results.

AES17 specifies two types of IMD signals, DFD and SMPTE. DFD measures high frequency IMD with two tones spaced 2 kHz apart at or near the upper band-edge frequency, such as 18 kHz and 20 kHz. The AES17 SMPTE test measures low frequency IMD with 41 Hz and 7993 Hz sine waves with 4:1 amplitude ratio. In both cases the peak audio signal level must reach full-scale. The APx555 IMD (DFD) and IMD (SMPTE) measurements satisfy this requirement.

DFD stands for Difference Frequency Distortion. DFD is described in the standards IEC60118 and IEC60268. The DFD stimulus is two equal-level high-frequency tones f_1 and f_2 , centered on a frequency called the mean frequency, $(f_1+f_2)/2$. The tones are separated by a frequency offset called the difference frequency. The two tones intermodulate in a distorting converter to produce sum and difference frequencies. DFD selectively measures the 2nd and 3rd order intermodulation products, combines their values arithmetically, and provides a result that is the ratio of the sum of the products to a reference voltage defined as $2 \times$ the voltage of f_2 (effectively, the sum of f_1 and f_2) (Figure 18). In the APx500 implementation, the 4th and 5th order products are also measured and reported in the distortion product view (Figure 19).

SMPTE IMD is a technique for measuring IMD (intermodulation distortion) according to the SMPTE RP120-1983 standard. The stimulus is a strong low-frequency interfering signal (f_1) combined with a weaker high frequency signal of interest (f_2). f_1 was originally specified at 60 Hz and f_2 at 7 kHz, at a ratio of $f_1:f_2=4:1$. AES17 redefines f_1 and f_2 to avoid frequencies (see above) synchronous with standard sampling rates. The stimulus signal is the sum of the two sine waves. In a distorting converter, this stimulus results in an AM (amplitude modulated) waveform, with f_2 as the “carrier” and f_1 as the modulation (Figure 21).

In analysis, f_1 is removed, and the residual is bandpass filtered and then demodulated to reveal the AM modulation products. The rms level of the modulation products is

measured and expressed as a ratio to the rms level of f2 (Figure 20). The SMPTE IMD measurement includes noise within the passband, and is insensitive to FM (frequency modulation) distortion.

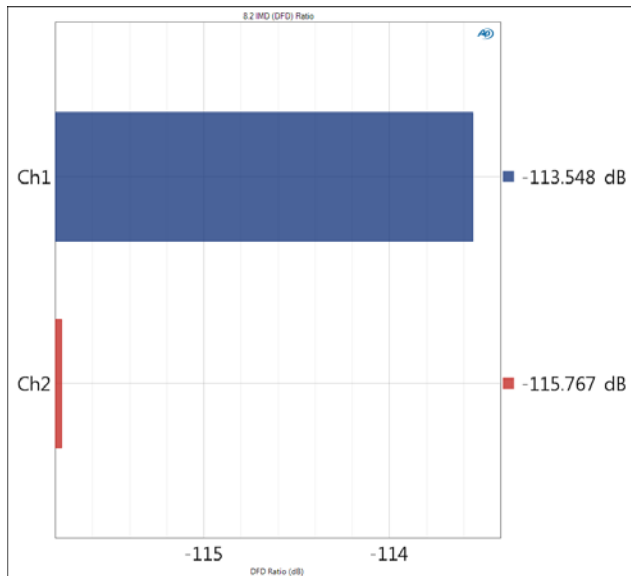


FIGURE 18. IMD (DFD)—TWIN-TONE INTERMODULATION DISTORTION

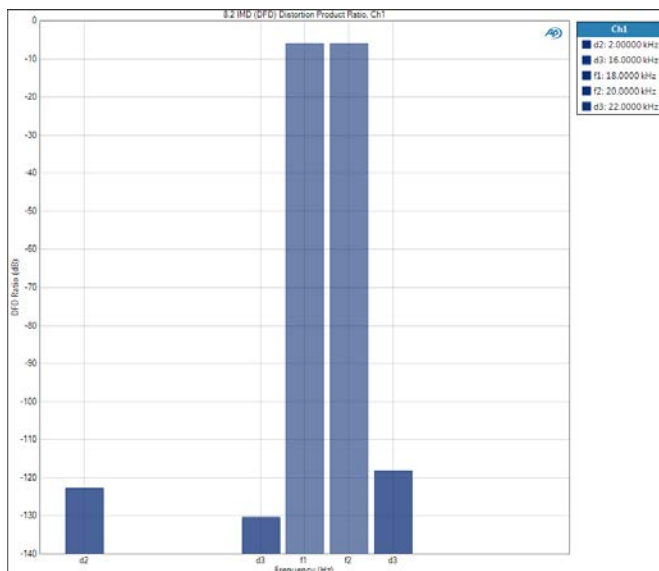


FIGURE 19. IMD (DFD)—DISTORTION PRODUCT RATIO

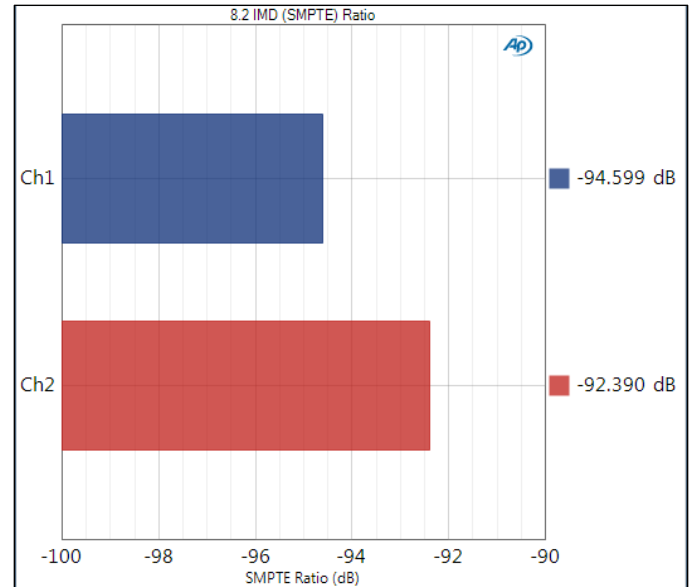


FIGURE 20. IMD (SMPTE)—LOW AND HIGH FREQUENCY SMPTE INTERMODULATION DISTORTION

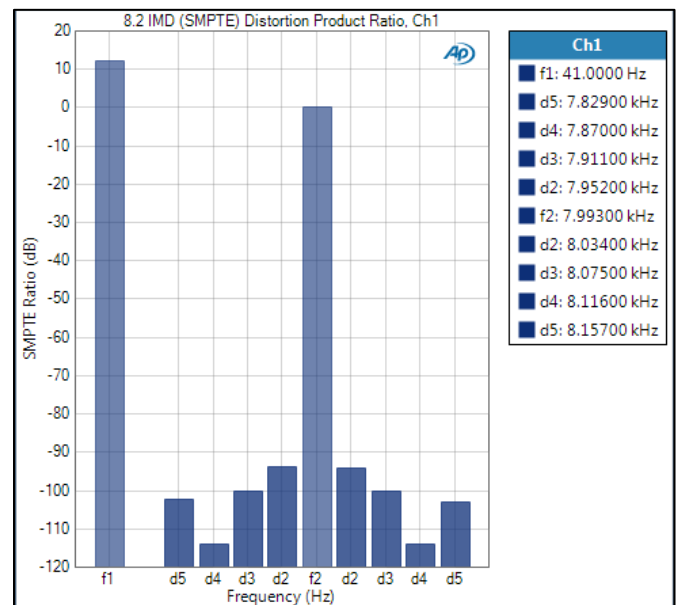


FIGURE 21. IMD (SMPTE)—DISTORTION PRODUCT RATIO

Jitter Frequency Sweep

Jitter Frequency Sweep is used for AES17 test 5.8.2 Digital-to-Analog Jitter Susceptibility.

Jitter Frequency Sweep generates an audio stimulus signal and a calibrated jitter sine wave magnitude at the APx555 digital output; sweeps the jitter frequency from a start frequency to a stop frequency; and measures audio parameters at the output of the converter.

The jitter frequency sweep is repeated for three digital audio sine wave frequencies. This combination of sweeps is called a “nested sweep”.

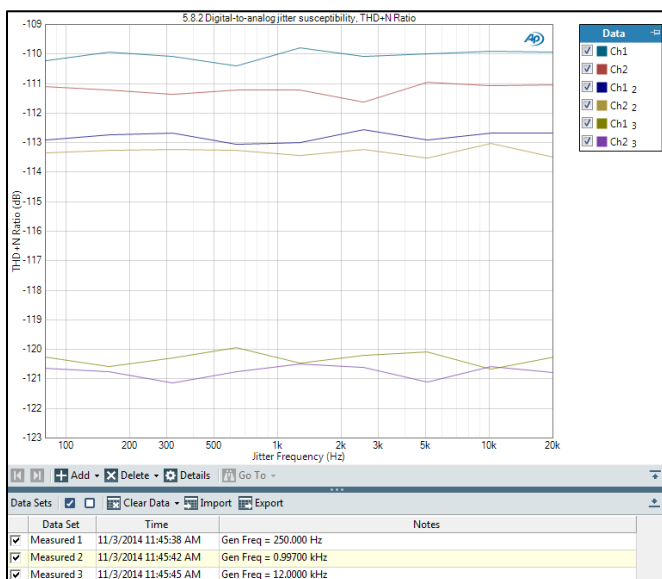


FIGURE 22. JITTER FREQUENCY SWEEP – OUTPUT THD+N VS. JITTER FREQUENCY VS. AUDIO FREQUENCY

Figure 22 above shows the AES17 Jitter Susceptibility test THD+N measurement results for a D-to-A converter. The X axis is the jitter frequency. The upper THD+N curves (Ch1₁ and Ch2₁) are THD+N Ratio distortion data with the APx555 digital audio generator at 250 Hz. Figure 23 shows the Jitter Frequency Sweep setup panel.

Audio Generator
Waveform: Sine

☒ Levels Track Ch1

Level: Ch1: -3.000 dBFS
DC Offset: 0.000 D

Frequency: 12.0000 kHz

Jitter Generator
Waveform: Sine
Start Frequency: 80.0000 Hz
Stop Frequency: 20.0000 kHz
Sweep: Custom
Points: 9

☒ Sec
☐ UI

Peak Level: 40.00 ns
Channels: 1 2

Analyzer
☒ High-pass Filter: 20 Hz
☒ Low-pass Filter: 20 kHz
☐ Weighting Filter: None
Phase Ref Channel: Ch1

Nesting
Secondary Source: Gen Freq
Start: 250.000 Hz
Stop: 12.0000 kHz
Sweep: Custom
Points: 3

FIGURE 23. JITTER FREQUENCY SWEEP—SETUP FOR AES17 5.8.2 D-TO-A JITTER SUSCEPTIBILITY TEST

Level and Gain

Level and Gain is used to test AES17 6.3 Output Amplitude at Full Scale for D-to-A converters.

Level and Gain - Jitter

Level and Gain with analyzer input set to Jitter is used to measure digital jitter at the output of an A-to-D converter connected to the APx555 balanced (AES/EBU), unbalanced (S/PDIF), or optical (TOSLink) digital audio inputs. Jitter may be measured in Unit Interval (UI) or seconds. The jitter is extracted from the clock or digital interface and routed to all APx measurements and meters.

Level Ratio

Level Ratio is used to test Interchannel Gain Mismatch with a -1 dBFS input at 997 Hz. It measures the level of all channels relative to a reference channel, expressed in dB.

Measurement Recorder

Measurement Recorder is used to test AES17 5.6 Input Logarithmic Gain Stability. The Measurement Recorder acquires audio measurements as a function of time in user defined time increments.

For the Input Logarithmic Gain Stability test, the time span is set for 60 minutes with measurements at 10 second intervals. The resulting graph of RMS Level vs. time may be processed with Minimum and Maximum derived results to produce two numbers that represent the highest and lowest output levels over the 60 minute period. The graph can be configured to display the entire measurement interval or scroll a time window with the most recent measurement at the right edge of the graph.

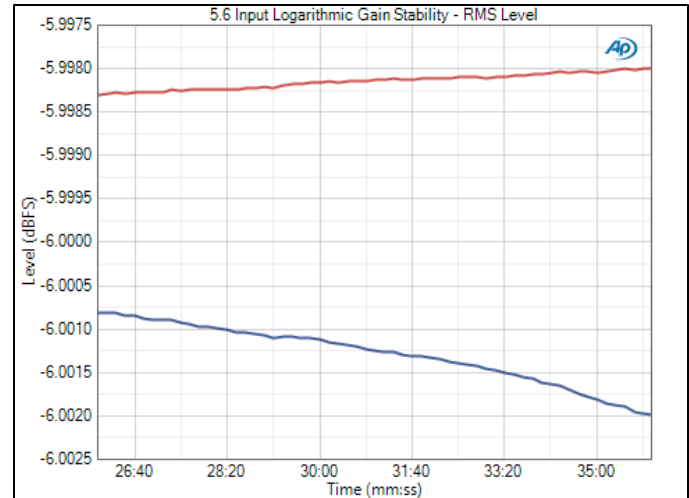


FIGURE 24. MEASUREMENT RECORDER – MEASUREMENTS VS. TIME

Noise (RMS)

The Noise (RMS) measurement is used to test AES17 9.1 Idle Channel Noise. Noise (RMS) provides High-Pass, Low-Pass, and Weighting filters to measure noise. The Idle Channel Noise test measures output from the converter with no input signal, with the Low Pass filter set to the folding frequency and CCIR-2K weighting filter.

Regulated Frequency Sweep

Regulated Frequency Sweep is used to measure AES17 tests 5.4 Input for Full-scale Amplitude and 5.5 Maximum Input Amplitude.

Regulated Frequency Sweeps use a sine wave stimulus signal that is stepped across a range of frequencies in a specified number of points. At each point, the generator level is adjusted to the audio level or THD+N Ratio distortion that achieves a target value in a selected channel.

The AES17 5.4 Input for Full-scale Amplitude test requires the Regulated Frequency Sweep measurement to be set for a target audio output level of 0.0 dBFS with a generator maximum limit set to a level 1 dB above the expected full scale input to the A-to-D converter. The measurement result is the audio input level required (the APx analog generator output level) to achieve full scale output of the converter, as a function of frequency.

The AES17 5.5 Maximum Input Amplitude test requires the Regulated Frequency Sweep measurement to be set for a target audio THD+N distortion of 1 % with a maximum

generator input of +3 dB above the expected full scale input to the converter. The measurement result is the audio input level required (the APx analog generator output level) to produce 1 % THD+N distortion.

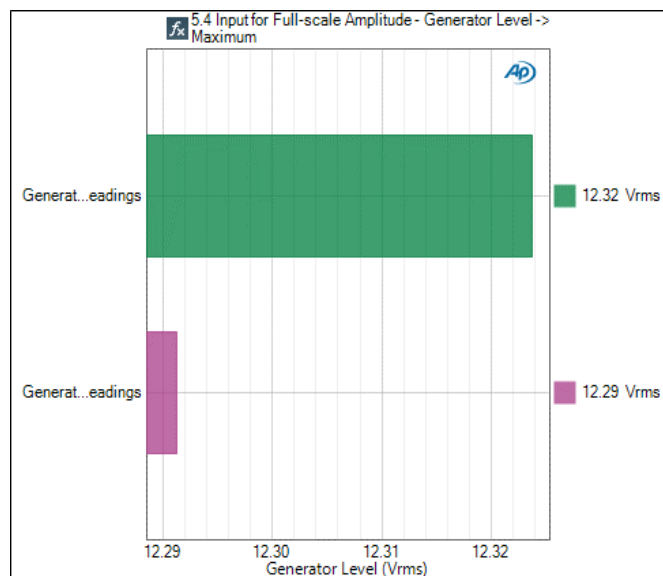


FIGURE 25. REGULATED FREQUENCY SWEEP—AES17 5.4 INPUT FOR FULL-SCALE AMPLITUDE, APX555 GENERATOR LEVEL MAXIMUM (DERIVED RESULT)

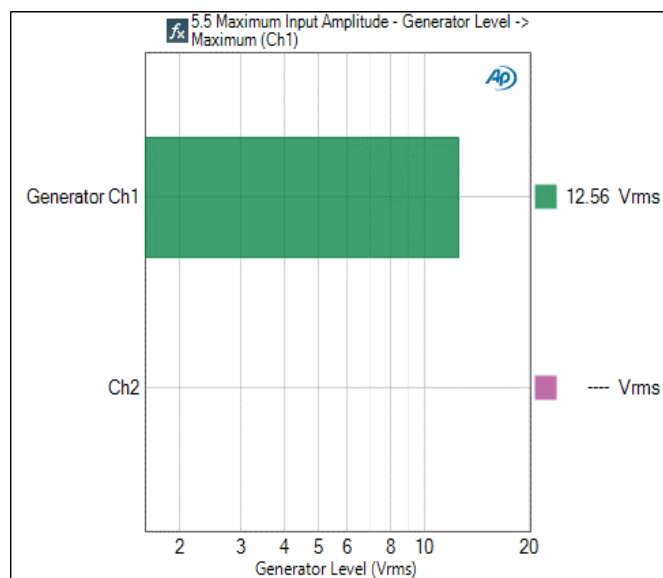


FIGURE 26. REGULATED FREQUENCY SWEEP—AES17 5.5 MAXIMUM INPUT AMPLITUDE, APX555 GENERATOR LEVEL MAXIMUM (DERIVED RESULT)

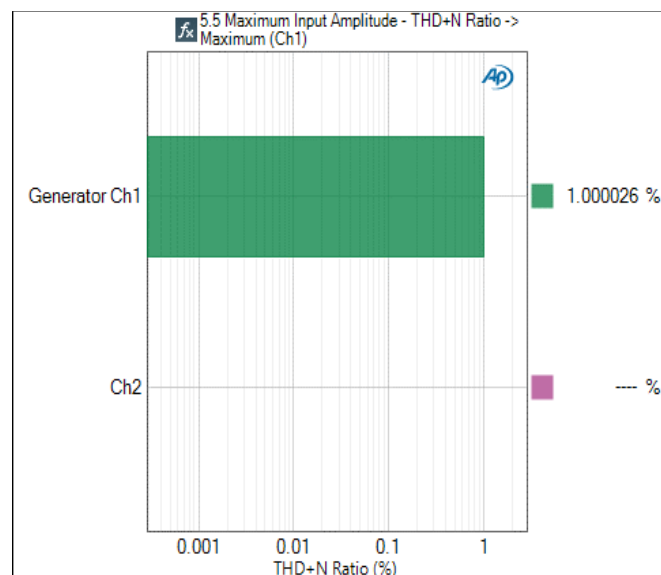


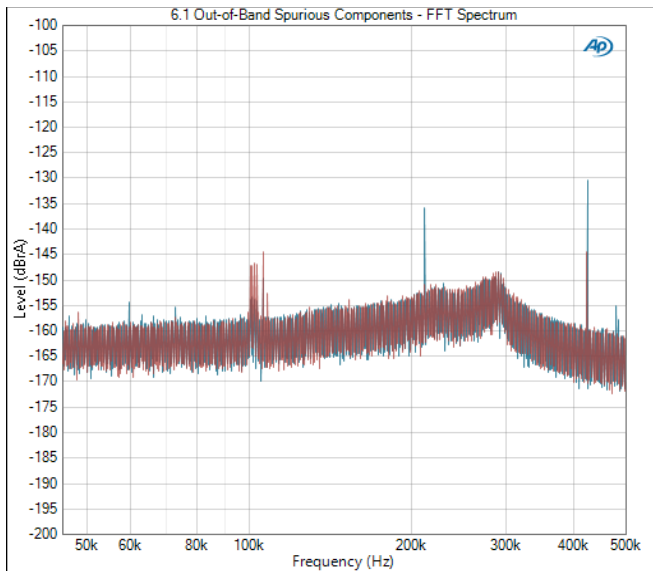
FIGURE 27. REGULATED FREQUENCY SWEEP—AES17 5.5 MAXIMUM INPUT AMPLITUDE, CONVERTER OUTPUT THD+N DISTORTION

Signal Analyzer (FFT and Waveform)

Signal Analyzer acquires audio or jitter signals and produces waveform and FFT spectrum graphs. The FFT graphs may be used in many converter tests to supplement test results and provide insight into the performance of the converter, beyond the limited information produced with swept bandpass measurements.

Signal Analyzer is used to measure AES17 tests 6.1 Out-of-Band Spurious Components for A-to-D converters, 9.4 Power-Line (mains) Related Products, 10.2 Non-linear HF and LF Interchannel Crosstalk for A-to-D converters, and supplements AES17 tests 8.2 IMD (DFD), and 9.2 Idle Channel Noise Spectrum.

The APx555 Signal Analyzer measurement of AES17 test 6.1 Out-of-Band Spurious Components for D-to-A converters takes advantage of the 500 kHz analyzer bandwidth to reveal high frequency spurious components with a frequency resolution of 1.0 Hz. This is possible with an FFT length setting of 1.2 M points and analog input bandwidth set to 500 kHz on two channels.



**FIGURE 28. SIGNAL ANALYZER—
D-TO-A OUT-OF-BAND SPURIOUS COMPONENTS TO 500 KHZ.**

The Signal Analyzer measurement of AES17 10.2 Non-Linear Interchannel Crosstalk for A-to-D converters utilizes the Sine, Dual waveform with the Split mode enabled to create IMD tones in two different channels with different frequencies and levels. The setup shown in Figure 29 illustrates the correct configuration for the AES17 10.2 Non-linear HF Interchannel Crosstalk measurement.

The graph in Figure 30 shows no 3 kHz intermodulation non-linear crosstalk components in the spectrum of channel 1 when it is driven at -20 dBFS while all other channels are driven at +3 dBFS, above the full scale input level.

▶ Start

☐ Append Graph Data

• Generator

Waveform: Sine, Dual

☐ Levels Track Ch1

	Level	DC Offset
Ch1 (A):	-20.000 dBrg	0.000 V
Ch2 (B):	+3.000 dBrg	0.000 V

Frequency A: 24.0000 kHz

Frequency B: 21.0000 kHz

☐ Sum ☒ Split

FB:FA Level Ratio: 1.000 x/y

Channel Assignments: A/B

1 2

• Analyzer

Acq Length: Auto

FFT Length: 16K

FFT Window: AP-Equiripple

Trigger: Free Run

Averages: Power 1

• Nesting

Secondary Source: None

Advanced Settings...

**FIGURE 29. SIGNAL ANALYZER WITH SPLIT MODE SINE, DUAL WAVEFORM
SETUP FOR NON-LINEAR HF INTERCHANNEL CROSSTALK.**

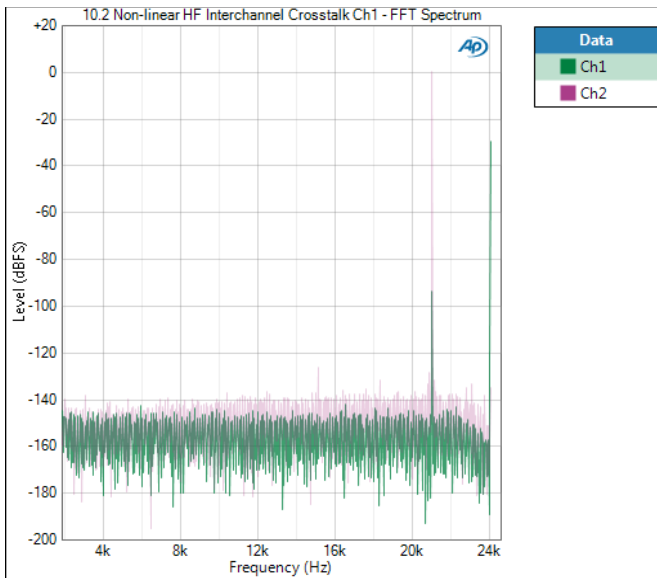


FIGURE 30. SIGNAL ANALYZER—SPLIT MODE SINE, DUAL NON-LINEAR CROSSTALK SPECTRUM

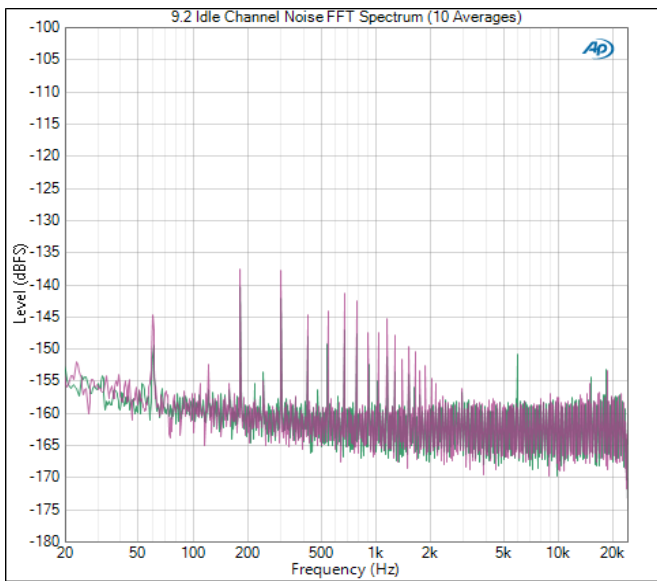


FIGURE 31. SIGNAL ANALYZER—FFT SPECTRUM OF IDLE CHANNEL NOISE

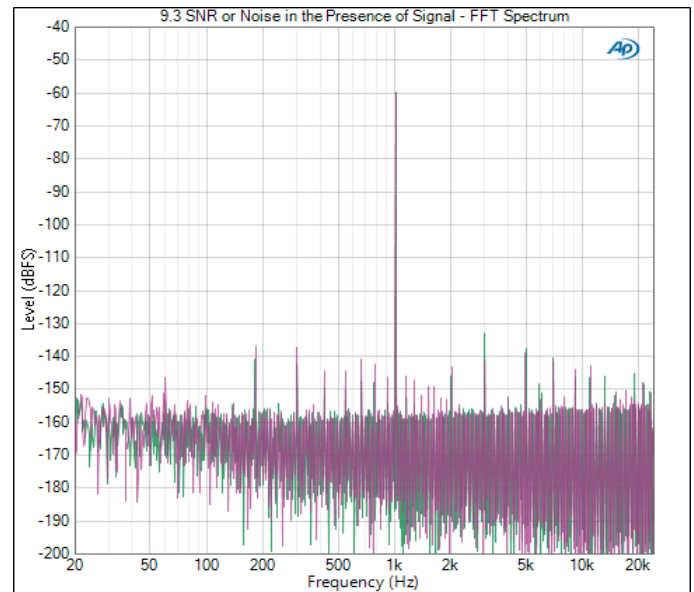


FIGURE 32. SIGNAL ANALYZER—OUTPUT SPECTRUM OF -60 DBFS DYNAMIC RANGE SIGNAL

Signal Analyzer - Jitter

Signal Analyzer with input set to Jitter performs spectrum analysis of APx555 input jitter from the digital output of an A-to-D converter.

Jitter maybe characterized by examining its frequency spectrum and identifying the significant frequency components. The APx555 received jitter signal is extracted from the digital output of the converter PCM interface and processed to produce a spectrum and waveform display.

The spectrum in Figure 33 is the result of an audio 997 Hz sine wave input at 0 dBFS. The spectrum of jitter at the digital output of the converter operating at 48 kHz sample rate displays prominent jitter components at 192 kHz and 96 kHz. The jitter magnitude at 96 kHz is 0.00212 UI. Figure 34 shows the jitter spectrum with a 997 Hz square wave audio input to the converter. Both measurements are 256 K FFTs with 10 averages.

The APx audio monitor routes the detected jitter signal to the PC audio system to permit monitoring with a speaker or headphone.

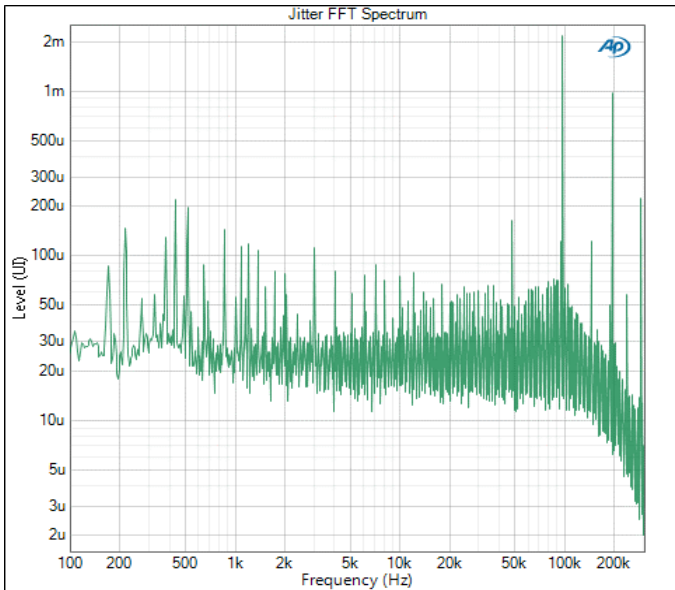


FIGURE 33. SIGNAL ANALYZER JITTER SPECTRUM WITH 0 DBFS 997 HZ SINE WAVE INPUT

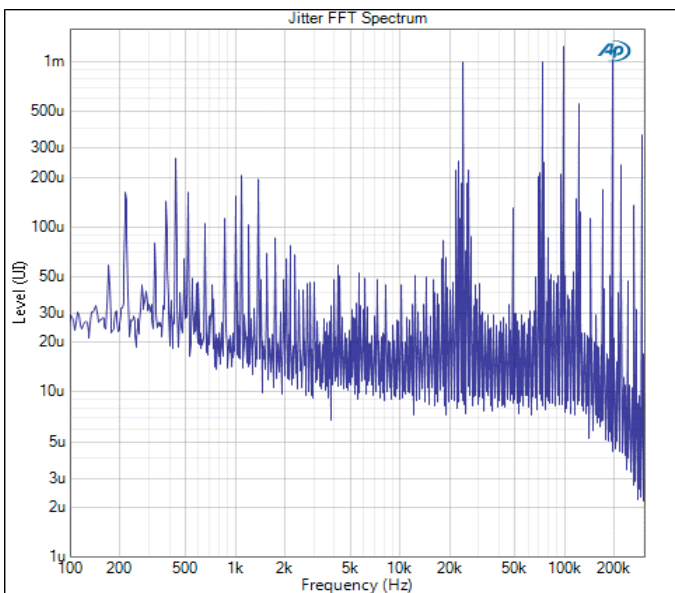


FIGURE 34. SIGNAL ANALYZER JITTER SPECTRUM WITH 0 DBFS 997 HZ SQUARE WAVE INPUT

Signal-to-Noise Ratio

Signal-to-Noise Ratio (SNR) is often included in databook specifications for IC components and complete converter products. SNR is actually two measurements: first, of the signal level; and second, of the noise level with the signal turned off. These two measurements are expressed as a dB ratio. Like most noise measurements, the SNR results are typically bandpass limited using high and low pass filters, or a weighting filter. SNR for converter measurements is usually performed with a 20 Hz High-pass filter, 20 kHz Low-pass filter, and A-weighting filter.

Stepped Frequency Sweep

Stepped Frequency Sweep is used for AES17 tests 5.1 Suppression of Aliasing Components, 7.1.1 Frequency Response, 7.2.3 Interchannel Phase Response, 8.5.1 THD+N vs. Frequency (at -1 and -20 dBFS input), Passband, and Stopband Attenuation vs. Frequency.

The Stepped Frequency Sweep measurement uses a sine wave stimulus signal swept across a range of frequencies in a series of discrete frequency steps. The converter output is acquired at each frequency step by the analyzer and processed for display. The 204 kHz frequency range of the APx555 Stepped Frequency Sweep measurement permits driving the input of an A-to-D converter beyond the folding frequency in order to see the stopband performance (Figure 36).

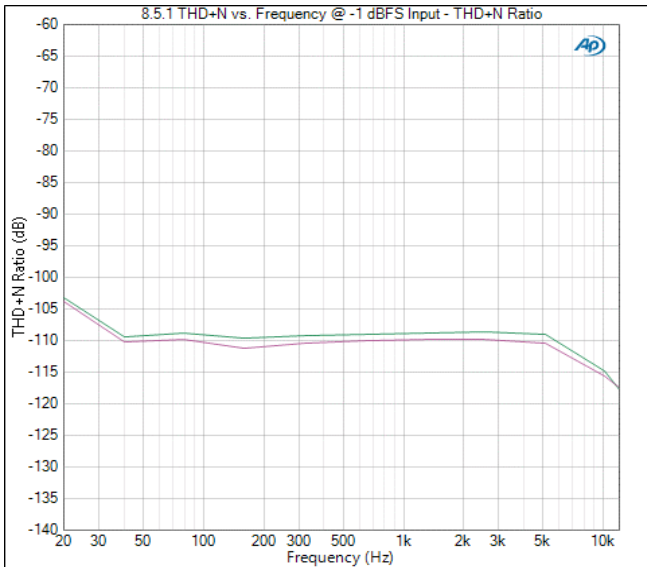


FIGURE 35. STEPPED FREQUENCY SWEEP-THD+N VS. FREQUENCY

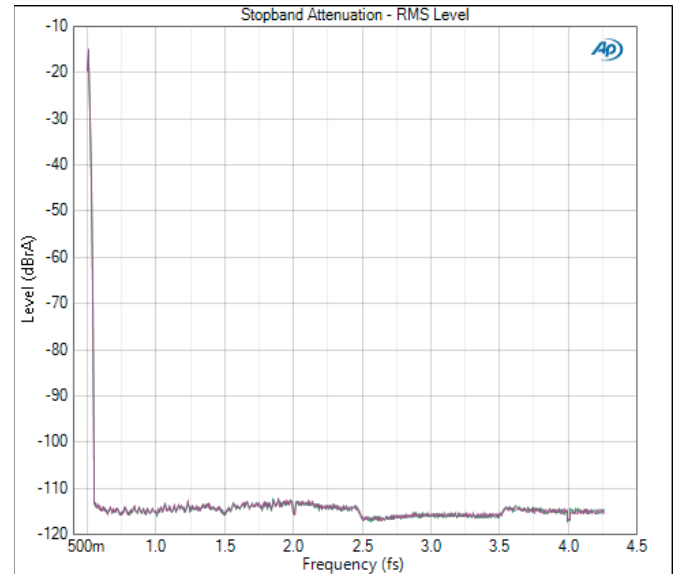


FIGURE 37. STEPPED FREQUENCY SWEEP-A-TO-D CONVERTER STOPBAND ATTENUATION WITH 0 DBFS INPUT SIGNAL (FREQUENCY SCALED IN FS RELATIVE TO 48 KHZ SAMPLE RATE)

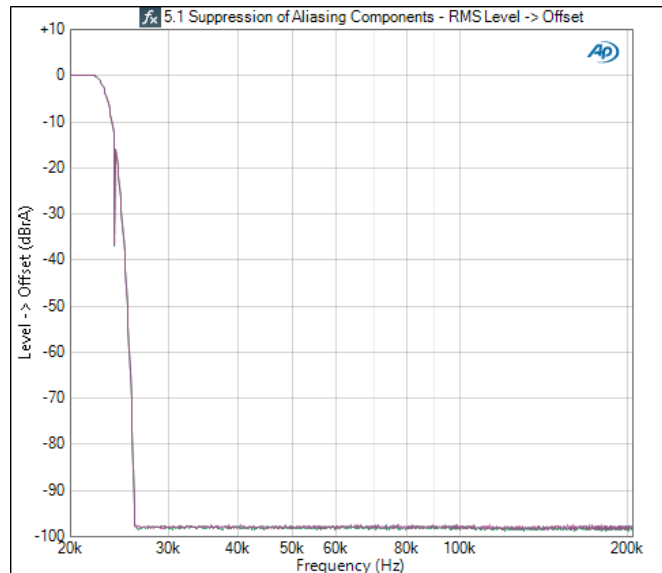


FIGURE 36. STEPPED FREQUENCY SWEEP-SUPPRESSION OF ALIAS COMPONENTS WITH -20 DBFS INPUT SIGNAL (48 KHZ SAMPLE RATE)

Stepped Level Sweep

The Stepped Level Sweep is used to test AES17 tests 5.3 Overload and 8.5.2 THD+N vs. Level.

The Stepped Level Sweep measurement uses a sine wave stimulus signal that is moved across a range of levels in a series of steps. The converter output is acquired by the analyzer and processed for display. The X-axis is the generator level or the measured level; the Y-axis is the converter output.

Figure 38 shows cursors placed at the generator -3 dB and +3 dB X values. The Y Delta value between the cursors indicates a converter overload distortion of 95.33 dB.

APx555 Measurement Project for A-to-D Converters

This technote provides a set of APx project files that perform AES17 measurements and databook measurements common to most A-to-D converter IC manufacturer specifications.

The APx project file “TN124 ADC 48k.approx” contains the Sequence Mode measurements shown in Table 1 below. This project file is designed for 48 kHz sample rate testing with an AES3 balanced digital output connector.

The APx project file “TN124 ADC 192k.approx” performs the same measurements for 192 kHz sample rate testing with higher frequency ranges for certain tests.

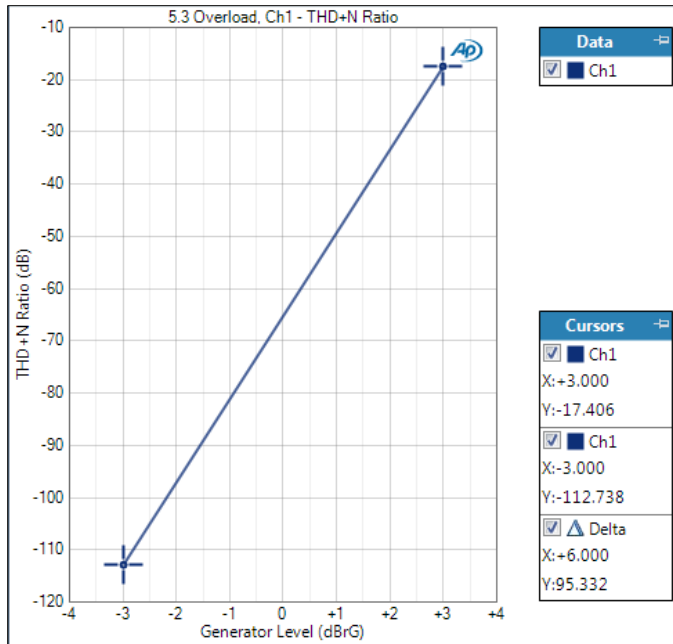


FIGURE 38. STEPPED LEVEL SWEEP—A-TO-D CONVERTER OVERLOAD DISTORTION

Figure 39 shows an A-to-D converter THD+N Ratio distortion at the output versus the input voltage (relative to full scale input). Input voltage is shown on the X-axis in dB relative to full scale input. As expected, the converter distortion decreases from left to right with increasing input level up to -3 dBFS input (the minimum dip in the curve). Above -3 dB input the output distortion increases to -58 dB at 0 dBFS full scale input (0 dBrG).

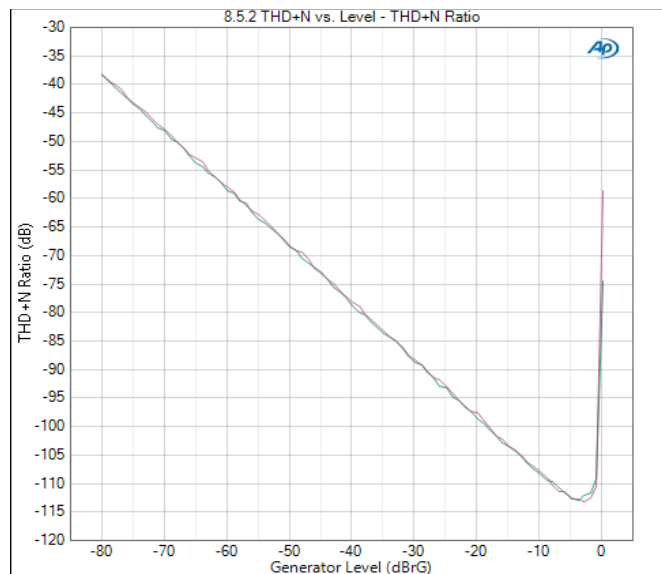


FIGURE 39. STEPPED LEVEL SWEEP—THD+N vs. INPUT LEVEL

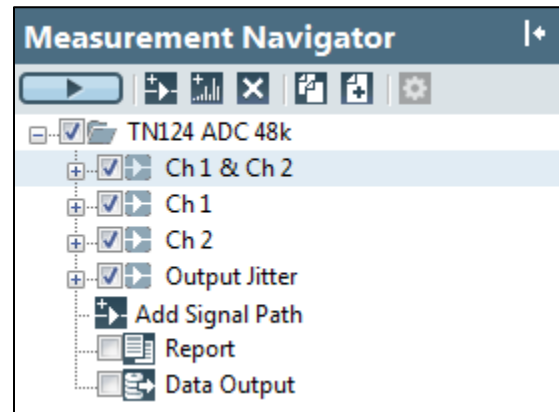


FIGURE 40. ADC PROJECT SIGNAL PATHS

Signal Paths consist of a hierarchy of Signal Path Setup and a sequence of one or more measurements, each containing measurement results.

The projects consists of four signal paths (Figure 40 above).

- Ch 1 & Ch 2
Simultaneous measurement of two channels. The dBrG input level reference assumes both channels have identical full scale input levels. Do not use this if the two channels have different full scale input levels.
- Ch 1
Measurement of A to D channel 1 only. A to D input channel 1 input must be connected to APx555 generator output channel 1. The dBrG input level reference is valid for generator channel 1 only. Channel 2 is not measured. Use this when the full scale input level of channel 1 is different from

channel 2. Interchannel measurements are not performed.

- Ch 2
Measurement of A to D channel 2 only. Channel 2 input must be connected to APx555 generator output channel 2. The dBrG level reference is valid for generator channel 2 only. A to D channel 1 is not measured. Use this when the full scale input level of channel 2 is different from channel 1. Interchannel measurements are not performed.
- Output Jitter

The Start Sequence button  starts execution of all check-marked signal paths and all check-marked measurements in the sequence, in descending order from top to bottom.

Only Signal Paths and Measurement items with check marks will be executed when the Start Sequence button is selected.

Check-mark the Report item to create a report containing all measurement results and graphs when the sequence completes execution. Reports are automatically saved to the folder containing the loaded APx project file.

Input Level Reference Setup

Each signal path automatically determines the maximum input level that results in a full scale 0 dBFS output at 997 Hz. The value determined is set as the level for the dBrG reference. Each measurement within a signal path specifies the APx555 analog generator output level in terms of dBrG rather than Vrms in order to simplify setup, therefore all measurements stimulate the A-to-D converter inputs at full scale or dB referenced to full scale input. If a different full scale reference is desired, change only the dBrG reference value in the References menu and all measurements will inherit the new input level for the converter.

At sequence run time the Signal Path Setup measurement will invoke the **Auto Gen Level...** function to drive the analog generator output level up or down to find the designated target level of 0.0 dBFS at the output of the converter, within a maximum specified generator output level.

The analog generator maximum level in this project file has been set to 26.66 Vrms in order to test a commercial A-to-D converter with maximum full scale input level of +29 dBu (22 Vrms). The additional +4 dB level margin is

recommended in order to perform the AES17 10.2 Nonlinear Crosstalk tests. If your device requires a lower input level to avoid damage, change the generator maximum level for safe operation.

To change the maximum level of the generator or to change the target measured level, select the **Auto Gen Level...** button on the Signal Path Measurement, References panel (Figure 42). Change the Maximum Level and Target Level settings as desired (Figure 41).

Select the **Set Generator Level** button to start the process. If successful the dBrG value in the Output References panel will be updated to the generator level required to achieve the target level. Then save the project to keep these settings.

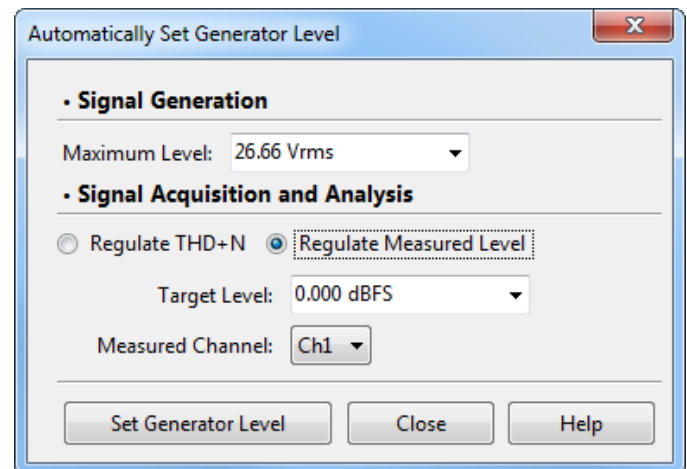


FIGURE 41. AUTOMATICALLY SET GENERATOR LEVEL

References

References

• Output References

dBrG: 22.18 Vrms
dBrm: 600.0 ohm
W(watts): 8.000 ohm
Auto Gen Level...

• Input References

dBr

Reference Offset

dBrA: 0.000 dBFS
0.000 dB
0.000 dBFS = 0.000 dBrA

dBrB: 0.000 dBFS
0.000 dB
0.000 dBFS = 0.000 dBrB

Set dBr...

dB SPL

Calibrator Level

dBSPL1: -40.000 dBFS
94.000 dB SPL
-40.000 dBFS = +94.000 dB SPL1

dBSPL2: -40.000 dBFS
94.000 dB SPL
-40.000 dBFS = +94.000 dB SPL2

Mic Cal / dB SPL...

• Frequency Reference

Frequency: 1.00000 kHz

FIGURE 42. REFERENCES PANEL

A-to-D Measurements

A-to-D measurements are shown below in Table 1. The second column of the chart indicates the APx measurement type and the result measurements. AES17 measurements are named with the relevant AES17 section number. Refer to the AES17 standard document for details on how these measurements are defined. Measurements without the AES17 section number are typical databook measurements that may differ from AES17.

Table 1 A-to-D Measurements (48 kS/s)

A-to-D Measurement	APx Measurement/Result
5.1 Suppression of Aliasing Components	Stepped Frequency Sweep 24 kHz to 192 kHz, 100 Hz steps -20 dBFS Reference Level RMS Level
5.3 Overload	Stepped Level Sweep THD+N Ratio
5.4 Input for Full-scale Amplitude	Regulated Frequency Sweep Generator Level -> Maximum RMS Level -> Maximum
5.5 Maximum Input Amplitude Ch1	Regulated Frequency Sweep Generator Level -> Maximum THD+N Ratio -> Maximum
5.5 Maximum Input Amplitude Ch2	Regulated Frequency Sweep Generator Level -> Maximum THD+N Ratio -> Maximum
5.6 Input Logarithmic Gain Stability	Measurement Recorder 60 minutes duration, 10 second measurement interval RMS Level RMS Level -> Minimum RMS Level -> Maximum
7.1.1 Frequency Response	Frequency Response Relative Level (0.99700 kHz) Deviation (10.0000 Hz - 20.0000 kHz) Passband Ripple—Relative Level (1 kHz)
7.1.1 Frequency Response	Stepped Frequency Sweep Relative Level (0.99700 kHz) Deviation (10.0000 Hz—20.0000 kHz)

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A-to-D Measurement	APx Measurement/Result
7.2.1 Phase Response	Continuous Sweep Input-to-Output Phase vs. Frequency (excess) Group Delay vs. Frequency Delay derived from Group Delay -> Data Distribution Interchannel Phase (Ch2 relative to Ch1) vs. Frequency Polarity - Impulse Response (a positive impulse indicates positive polarity), requires operator Pass or Fail acknowledgement.
7.2.2 Group Delay	
7.2.3 Interchannel Phase Response	
7.3 Delay	
7.4 Polarity	
8.1 Level Dependent Logarithmic Gain	Bandpass Level Sweep AES17 Level-dependent Logarithmic-Gain
8.2 IMD (DFD)	IMD (DFD) DFD Ratio DFD Distortion Product Ratio
8.2 IMD (DFD) Spectrum	Signal Analyzer (FFT) 8.2 IMD Spectrum (wideband to folding frequency) 8.2 IMD Spectrum D2 & D3 (narrow band to 5 kHz)
8.2 IMD (SMPTE)	IMD SMPTE SMPTE Ratio SMPTE Distortion Product Ratio, Ch1 SMPTE Distortion Product Ratio, Ch2
8.5.1 THD+N vs. Frequency @ -1 dBFS	Stepped Frequency Sweep THD+N Ratio
8.5.1 THD+N vs. Frequency @ -20 dBFS	Stepped Frequency Sweep THD+N Ratio
8.5.2 THD+N vs. Level	Stepped Level Sweep THD+N Ratio
9.1 Idle channel Noise	Noise (RMS) Noise Level
9.2 Idle Channel Noise Spectrum	Bandpass Frequency Sweep RMS Level
9.2 Idle Channel Noise Spectrum	Signal Analyzer (FFT) FFT Spectrum Amplitude Spectral Density

A-to-D Measurement	APx Measurement/Result
9.3 SNR or Noise in the Presence of Signal	Dynamic Range - AES17
9.3 DNR Spectrum	Signal Analyzer (FFT) FFT Spectrum
9.4* Power-line (mains) related products *FFT spectrum only	Signal Analyzer (FFT) FFT Spectrum (20 Hz to 500 Hz) 50 Hz AC mains products 60 Hz AC mains products
10.1 Interchannel Crosstalk Sweep, One Channel Driven	Crosstalk Sweep, One Channel Driven Crosstalk Ch1 – Ch2 Driven Crosstalk Ch2 – Ch1 Driven
10.2 Non-linear HF Interchannel Crosstalk Ch1	Signal Analyzer (FFT) FFT Spectrum Specify Data Points and graph delta cursors provides the 2 nd & 3 rd order levels relative to the 24 kHz fundamental
10.2 Non-linear HF Interchannel Crosstalk Ch2	Signal Analyzer (FFT) FFT Spectrum Specify Data Points and graph delta cursors provides the 2 nd & 3 rd order levels relative to the 24 kHz fundamental
10.2 Non-linear LF Interchannel Crosstalk Ch1	Signal Analyzer (FFT) FFT Spectrum Specify Data Points provides the sideband amplitude levels relative to the 12 kHz fundamental
10.2 Non-linear LF Interchannel Crosstalk Ch2	Signal Analyzer (FFT) FFT Spectrum Specify Data Points provides the sideband amplitude levels relative to the 12 kHz fundamental
Interchannel Gain Mismatch	Level Ratio
Common Mode Rejection Ratio	CMRR IEC CMRR Pin 2 CMRR Pin 3
Signal-to-Noise Ratio	Signal to Noise Ratio 20 Hz–20 kHz A-weighted 0 dBrG (full scale input)

A-to-D Measurement	APx Measurement/Result
Passband @ -0.1 dBFS Input	Frequency Response (1 KHz to 23.756 kHz) Passband Ripple—Relative Level (1 KHz) (level scale +0.1 to -1.0 dBFS) Relative Level (1 kHz) (frequency scale 19.2 kHz to 25 kHz)
Passband @ -0.1 dBFS Input	Stepped Frequency Sweep (1 kHz to 24.0 KHz, 100 Hz increments) Passband Ripple - Relative Level (1 kHz) (level scale +0.1 to -1.0 dBFS) Passband Frequency - Relative Level (1 kHz) (frequency scale 19.2 kHz to 25 kHz)
Stopband Attenuation vs. Frequency	Stepped Frequency Sweep RMS Level
Output Jitter	Jitter Level RMS, Peak, and Average With AES3 Jitter (50) High Pass Filter.
Output Jitter Spectrum	Signal Analyzer Jitter spectrum

document for details on how these measurements are defined. Measurements without the AES17 section number are typical databook measurements that may differ from AES17.

The project consists of three signal paths (Figure 43), configured for high bandwidth tests (up to 500 kHz), AC input coupled tests, and DC input coupled tests.

DC input coupling is appropriate for measurements at 10 Hz in order to avoid low frequency roll off that would occur if the APx555 analyzer inputs were AC coupled.

Use the Start Sequence Execution button  to begin execution of all check-marked signal paths.

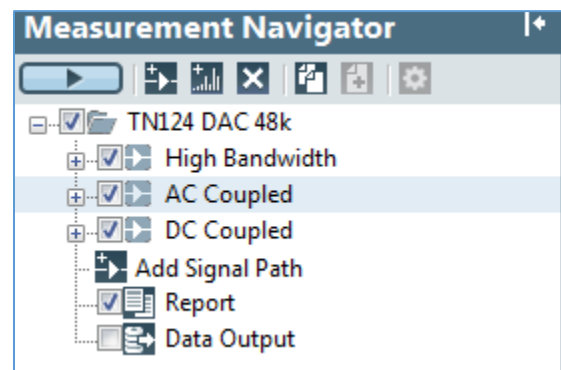


FIGURE 43. DAC PROJECT SIGNAL PATHS

Each signal path automatically determines the DAC full scale output voltage levels by driving the inputs at 0.0 dBFS with a 997 Hz sine wave and setting the dBrA and dBrB reference values. These dBr units then represent the D-to-A converter output in terms of full scale at 997 Hz.

APx555 Measurement Project for D-to-A Converters

This technote provides an APx project file that performs AES17 measurements and databook measurements common to most D-to-A converter IC manufacturer specifications.

The APx project file “TN124 DAC 48k.approx” contains the Sequence Mode measurements shown in table 2. The project is designed for 48 kHz sample rate converters with an unbalanced S/PDIF digital input.

The APx project file “TN124 DAC 192k.approx” performs the same measurements for 192 kHz sample rate testing with higher frequency ranges for certain tests.

Table 2 AES17 measurements are named with the relevant AES17 section number. Refer to the AES17 standard

Table 2 D-to-A Measurements (48 kS/s)

D-to-A Measurement	APx Measurement/Result
5.8.2 Digital-to-analog jitter susceptibility	Jitter Frequency Sweep
6.1* Out-of-Band Spurious Components *Spectrum data only.	Signal Analyzer FFT Spectrum Amplitude Spectral Density
6.2* Suppression of Imaging Components (Spectrum) *Spectrum data only.	Signal Analyzer FFT Spectrum Ch 1 FFT Spectrum -> Maximum Ch 2 FFT Spectrum -> Maximum
6.3 Output Amplitude at Full Scale	Level and Gain RMS Level Gain
6.4 Maximum Output Amplitude 1% THD+N	Stepped Level Sweep RMS Level -> Maximum RMS Level THD+N Ratio vs Measured Level THD+N Ratio
6.5 Output-level Stability	Measurement Recorder 60 minutes duration, 10 second measurement interval RMS Level RMS Level -> Minimum RMS Level -> Maximum
7.1.1 Frequency Response	Frequency Response Relative Level (0.99700 kHz) Deviation (20.0000 Hz–20.0000 kHz) Passband Ripple – Relative Level (1.0 kHz)
7.1.2 Maximum signal level versus frequency	Regulated Frequency Sweep Target Level = –6.02 dBFS RMS Level (dBrA) Generator Level

D-to-A Measurement	APx Measurement/Result
7.2.1 Phase Response 7.2.2 Group Delay 7.2.3 Interchannel Phase Response 7.3 Delay 7.4 Polarity	Continuous Sweep Input-to-Output Phase vs. Frequency Phase—Interchannel Group Delay vs. Frequency Delay (Group Delay -> Data Distribution) Polarity (Impulse Response - a positive impulse indicates positive polarity), requires operator Pass or Fail acknowledgement.
7.2.3 Interchannel Phase Response	Stepped Frequency Sweep Phase
8.1 Level Dependent Logarithmic Gain, Idle Channel Noise @ 1 kHz	Bandpass Level 1 kHz third-octave band pass filtered idle channel noise reference level.
8.1 Level Dependent Logarithmic Gain	Bandpass Level Sweep Gain vs. Generator Level
8.2 IMD (DFD)	IMD (DFD) DFD Ratio DFD Distortion Product Ratio
8.2 IMD (DFD) Spectrum	Signal Analyzer (FFT) Spectrum (0 Hz to 24 kHz)
8.2 IMD (SMPTE)	IMD SMPTE SMPTE Ratio SMPTE Distortion Product Ratio, Ch1 SMPTE Distortion Product Ratio, Ch2
8.5.1 THD+N vs. Frequency @ –1 dBFS	Stepped Frequency Sweep THD+N Ratio
8.5.1 THD+N vs. Frequency @ –20 dBFS	Stepped Frequency Sweep THD+N Ratio
8.5.2 THD+N vs. Level	Stepped Level Sweep THD+N Ratio
9.1 Idle channel Noise	Noise (RMS) Noise Level
9.2 Idle Channel Noise Spectrum	Bandpass Frequency Sweep RMS Level

D-to-A Measurement	APx Measurement/Result
9.2 Idle Channel Noise Spectrum	Signal Analyzer (FFT) FFT Spectrum Amplitude Spectral Density
9.3 SNR or Noise in the Presence of Signal	Dynamic Range - AES17
9.3 DNR Spectrum	Signal Analyzer (FFT) FFT Spectrum
9.4* Power-line (mains) related products *FFT spectrum only	Signal Analyzer (FFT) FFT Spectrum (10 Hz to 500 Hz) 50 Hz AC mains products 60 Hz AC mains products
10.1 Interchannel Crosstalk Sweep, One Channel Driven	Crosstalk Sweep, One Channel Driven Crosstalk Ch1 – Ch 2 Driven Crosstalk Ch2 – Ch 1 Driven
Interchannel Gain Mismatch	Level Ratio
Signal-to-Noise Ratio	Signal to Noise Ratio 20 Hz–20 kHz A-weighted 0 dBrG (full scale input)
Passband @ -0.1 dBFS Input	Frequency Response 1 KHz to 23.759 kHz Passband Ripple - Relative Level (1 KHz) (level scale +0.1 to -1.0 dBFS) Relative Level (1 kHz) (frequency scale 19.2 kHz to 24 kHz)
Passband @ -0.1 dBFS Input	Stepped Frequency Sweep 1 kHz to 23.952 KHz, 10 Hz increments Passband Ripple - Relative Level (1 kHz) (level scale +0.1 to -1.0 dBFS) Passband Frequency - Relative Level (1 kHz) (frequency scale 19.2 kHz to 24 kHz)

