Federal Agencies
Digitization Guidelines Initiative

Audio Analog-to-Digital Converter Performance Specification and Test Method

Guideline (High Level Performance)

Version 1.1, February 2016

The FADGI Audio-Visual Working Group

http://www.digitizationguidelines.gov/audio-visual/

Audio Analog-to-Digital Converter Performance Specification and Test Method

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Scope and history

This document specifies a set of metrics and methods pertaining to the performance of the audio analog-to-digital converters (ADCs) used in preservation reformatting workflows. This 2016 version 1.1 is an update of version 1.0 of the guideline published in August 2012: *Audio Analog-to-Digital Converter Performance Specification and Test Method: Guideline (High Level Performance), v 1.0*, cited below.

Version 1.1 includes adjustments to the methods and pass-fail recommendations for several of the metrics and adds explanatory notes for Common-Mode Rejection Ratio and Alias Rejection. An item-by-item comparison of v 1.0 and v 1.1 is provided in the report titled *ADC Performance Testing: Report on Project Development During 2015*, cited below.

This guideline is one of six related documents pertaining to ADC system performance. The five companion documents are:

- *Audio Analog-to-Digital Converter Performance Specification and Test Method: Introduction* (August 2012). This is the main explanatory document.
    - http://www.digitizationguidelines.gov/audio-visual/documents/ADC_performIntro_20120820.pdf
- *ADC Performance Testing: Report on Project Development During 2015*. Expert Consultant Report for the Audio-Visual Working Group, Federal Agencies Digitization Guidelines Initiative, February 16, 2016. This report includes an explanation of the changes made to the 2012 guideline in order to produce the 2016 guideline.
    - http://www.digitizationguidelines.gov/audio-visual/documents/ADC-report_20160216.pdf.

- Federal Agencies Digitization Guidelines Initiative. *Audio Analog-to-Digital Converter Performance Specification and Test Method: Guideline (High Level Performance), v 1.0.* 2012 version.
  - http://www.digitizationguidelines.gov/audio-visual/documents/ADC_performGuide_20120820.pdf.
- *Assess Audio System Evaluation Tools: Consultant's Initial Report* (March 2011)
  - http://www.digitizationguidelines.gov/audio-visual/documents/FADGI_Audio_EvalPerf_Report.pdf
- Previous draft of the introductory discussion and performance guideline (February 2012)
  - http://www.digitizationguidelines.gov/audio-visual/documents/ADC_Perf_Test_2012-02-24.pdf

The Working Group's expert consultant Chris Lacinak (Audiovisual Preservation Solutions) was the principal investigator and main author for all of these documents. In the effort that led to this guideline, Lacinak worked closely with the audio engineer Phillip Sztenderowicz.[1] During earlier phases of this project, Lacinak received valuable guidance from a number of members of the Working Group and from outside experts, notably Richard Cabot[2] and Ian Dennis.[3]

ADC performance is the central element within the larger topic of audio digitization system performance, which also includes the problem of interstitial errors, where samples are dropped or otherwise altered in the final digital audio file, and consideration of the impact of other devices, cables, or interfaces that may be placed in the signal chain. Interstitial errors and their identification has been the subject of a separate investigation by the Working Group, with results published in 2013,[4] while the impact of other system elements is out of scope at this time.

The metrics specified in the guideline pertain to the production of files using the highest quality ADC devices. Comments from within and without the Working Group, however, have called attention to the range of types of archival organizations, some with strong resources and others in modest circumstances. Commentators have also noted the variation in the categories of material to be reformatted, asking if there might be circumstances in which relaxed levels of device performance would be acceptable. The Working Group's initial investigation of this topic is covered in *ADC Performance Testing: Report on Project Development During 2015*, cited above.

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[1] Sztenderowicz participated in this project under the auspices of Audiovisual Preservation Solutions; he also works as a technical engineer at Sterling Sound in New York.

[2] Richard C. Cabot has a Ph.D. from Rensselaer Polytechnic Institute and his professional career has included work at Tektronix, Audio Precision (which he co-founded), XFRM, Inc., and Qualis Audio. Cabot also chairs the committee that developed the AES-17 digital audio measurement standard.

[3] Ian Dennis is the co-founder and Chief Technical Officer at Prism Sound, a well-known manufacturer of digital audio systems.

[4] Main report: http://www.digitizationguidelines.gov/audio-visual/documents/Interstitial_Error_Report_2013-04-08.pdf. Appendixes: http://www.digitizationguidelines.gov/audio-visual/documents/Interstitial_Error_Appen_2012-09-11.pdf.

ADC Performance Guideline (High Quality)

<table>
<tr><td>Test Name</td><td>Frequency Response</td></tr>
<tr><td>Test Method</td><td>Frequency response shall be measured at –20 dBFS with a sinewave whose frequency varies from 10 Hz to 50 kHz in steps no larger than 10 per octave. Results should be reported as a graph and the greatest point of variation shall be documented in dB.</td></tr>
<tr><td>Performance Specification</td><td>
<table>
<tr><th>Sample Rate</th><th>Frequency</th><th>Limit</th></tr>
<tr><td>48kHz</td><td>20 – 20k Hz</td><td>+/- 0.1 dB</td></tr>
<tr><td>96kHz</td><td>20 – 20k Hz</td><td>+/- 0.1 dB</td></tr>
<tr><td>96kHz</td><td>20k - 40k Hz</td><td>+/- 0.5 dB</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td>Test Name</td><td>Total Harmonic Distortion + Noise (THD+N)</td></tr>
<tr><td>Test Method</td><td>The EUT shall be stimulated with a low distortion sine wave. The test signal present in the output shall be removed with a notch filter and bandwidth limited from 20 Hz to 20 kHz. The RMS amplitude is reported as a ratio to the RMS amplitude of the unfiltered signal. The measurement should be performed at the following amplitude and frequency combinations: -1.0 dBFS at 41 Hz, 997 Hz and 6597 Hz, –10 dBFS at 997 Hz, and -20 dBFS at 997 Hz, and -60 dBFS at 997 Hz.</td></tr>
<tr><td>Performance Specification</td><td>
<table>
<tr><th>Freq</th><th>Level</th><th>Limit (unweighted)</th></tr>
<tr><td>Hz</td><td>dBFS</td><td></td></tr>
<tr><td>41</td><td>-1</td><td>-95</td></tr>
<tr><td>997</td><td>-1</td><td>-95</td></tr>
<tr><td>6597</td><td>-1</td><td>-95</td></tr>
<tr><td>997</td><td>-10</td><td>-95</td></tr>
<tr><td>997</td><td>-20</td><td>-90</td></tr>
<tr><td>997</td><td>-60</td><td>-50</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td>Test Name</td><td>Dynamic Range (Signal to Noise)</td></tr>
<tr><td>Test Method</td><td>The measurement is the ratio of the full-scale amplitude to the weighted r.m.s. noise and distortion, expressed in dB, in the presence of signal. It includes all harmonic, inharmonic, and noise components. The test signal shall be a 997-Hz sine wave producing – 60 dBFS at the EUT output. Any 997-Hz test signal present in the output is removed by means of a standard notch filter. The remaining noise is filtered with an A weighting filter limited to 20 kHz. The results shall be reported as unweighted and A-weighted in dBFS.</td></tr>
<tr><td>Performance Specification</td><td>
<table>
<tr><th>Weighting</th><th>Limit</th></tr>
<tr><td>Unweighted</td><td>-110 dB</td></tr>
<tr><td>A weighted</td><td>-112 dB</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td>Test Name</td><td>Cross-Talk</td></tr>
<tr><td>Test Method</td><td>One channel of the EUT is driven with a -1 dBFS sinewave. The output of the other channels is passed through a narrow bandpass filter and the maximum amplitude of this frequency appearing in any other channel is noted. The measurement is repeated for each input channel and the maximum amplitude for all channels is determined. The measurement shall be performed at frequencies of 20 Hz, 997 Hz and 20 kHz, and shall be expressed as a ratio, in dB, between the output of the driven channel and the channel under test.</td></tr>
<tr><td>Performance Specification</td><td><table>
<tr><th>Frequency</th><th>Limit</th></tr>
<tr><td>20 Hz</td><td>-110 dB</td></tr>
<tr><td>997 Hz</td><td>-110 dB</td></tr>
<tr><td>20 k Hz</td><td>-105 dB</td></tr>
</table></td></tr>
</table>

<table>
<tr><td>Test Name</td><td>Common-Mode Rejection Ratio (CMRR)[5]</td></tr>
<tr><td>Test Method</td><td>The input shall be driven from a sinewave generator whose output impedance is less than 100 Ohms. The amplitude is adjusted to achieve -20 dBFS at the EUT output.

The signal generator should then be switched to a common-mode rejection test configuration. Typically this involves the low side signal being directed to the chassis and the high side signal being directed to both the high and low legs routed through well matched resistors (better than .003%). This results in the high and low legs carrying the same signal.

Substantial attenuation in the output measurement should be seen in this scenario, as the signal on the two legs should cancel (80 – 90dB of cancellation).

For balanced connections, following the output of the signal generator, the insertion of a 10 ohm resistor is alternated between legs and the leg yielding the highest EUT output level is noted. If the input is unbalanced, the resistor should be inserted on the high side.

The output shall be measured through a bandpass filter at the stimulus frequency. The resulting RMS value, measured in dBFS, is increased by 20 dB and reported as a positive dB value.

The measurement should be performed at 60 Hz, 997 Hz and 20 kHz.</td></tr>
</table>

[5] See the explanatory note about CMRR in appendix B.

<table>
<tr><td></td><td>Note that the limit is a lower limit, meaning that passing values are those which are greater than the stated limit.</td></tr>
<tr><td>Performance Specification</td><td><table><tr><th>Frequency</th><th>Limit</th></tr><tr><td>60 Hz</td><td>70 dB</td></tr><tr><td>997 Hz</td><td>70 dB</td></tr><tr><td>20 k Hz</td><td>50 dB</td></tr></table></td></tr>
</table>

<table>
<tr><td>Test Name</td><td>Low Frequency Intermodulation Distortion (LF IMD)</td></tr>
<tr><td>Test Method</td><td>IM measurements shall be performed with a twin tone signal consisting of 41 Hz and 7993 Hz in a 4:1 amplitude ratio. When summed the signal shall equal -1 dBFS at EUT output. The modulation sidebands below the 7993 Hz tone shall be measured by passing the signal through a 2 kHz high-pass filter and then demodulating, filtering and summing the sidebands. The resulting value shall be reported as a decibel value relative to the amplitude of the 7993 Hz tone.</td></tr>
<tr><td>Performance Specification</td><td><table><tr><th>Frequency</th><th>Limit</th></tr><tr><td>LF sum</td><td>-90 dB</td></tr></table></td></tr>
</table>

<table>
<tr><td>Test Name</td><td>High Frequency Intermodulation Distortion (HF IMD)</td></tr>
<tr><td>Test Method</td><td>IM measurements shall be performed with a twin tone signal consisting of 20 kHz and 18 kHz in a 1:1 amplitude ratio. When summed the signal shall equal -1 dBFS. The RMS sum of second- and third-order in-band difference frequency components (ie. 2k, 186, 22k) in the output are measured with a spectrum analyzer or narrow band-pass filter and reported in dB relative to the amplitude of the stimulus.</td></tr>
<tr><td>Performance Specification</td><td><table><tr><th>Frequency</th><th>Limit</th></tr><tr><td>HF sum</td><td>-100 dB</td></tr></table></td></tr>
</table>

<table>
<tr><td>Test Name</td><td>Amplitude Linearity</td></tr>
<tr><td>Test Method</td><td>A 997 Hz sinewave shall be swept from -5 dBFS to -105 dBFS, in steps no larger than 5dB. The amplitude of the output sinewave is measured using a narrow bandpass filter. The deviation in the measured amplitude relative to the the input amplitude is reported as a standard deviation value in dB.</td></tr>
<tr><td>Performance Specification</td><td><table><tr><th></th><th>Limit</th></tr><tr><td>Standard Deviation</td><td>0.05 dB</td></tr></table></td></tr>
</table>

<table>
<tr><td>Test Name</td><td>Spurious Inharmonic Signals</td></tr>
<tr><td>Test Method</td><td>A 997 Hz sinewave shall be applied at -1 dBFS. The output spectrum shall be measured with a 32k point fast Fourier transform (FFT) using a Rife-Vincent 5 window. The largest inharmonic component across all channels between 50 Hz and</td></tr>
</table>

<table>
<tr><td></td><td>24 kHz is reported in dBFS.[6]</td></tr>
<tr><td>Performance Specification</td><td><table><tr><th>Frequency</th><th>Limit</th></tr><tr><td>50Hz - 24 kHz</td><td>-130 dBFS</td></tr></table></td></tr>
</table>

<table>
<tr><td>Test Name</td><td>Alias Rejection[7]</td></tr>
<tr><td>Test Method</td><td>The device is stimulated with a variable frequency sine wave at -10 dBFS. Beginning at half the sample rate, the frequency is swept until it reaches 200 kHz. The rms amplitude at the converter output, increased by 10 dB, is graphed. Results are reported as the lowest frequency at which the alias component was equal to or greater in amplitude than all other alias components across the frequency range tested. Amplitude is expressed relative to the stimulus amplitude in dB.</td></tr>
<tr><td>Performance Specification</td><td><table><tr><th>SR</th><th>Limit</th></tr><tr><td>48 kHz</td><td>-80</td></tr><tr><td>96 kHz</td><td>-80</td></tr></table></td></tr>
</table>

<table>
<tr><td>Test Name</td><td>Sync Input Jitter Susceptibility</td></tr>
<tr><td>Test Method</td><td>The converter input is driven with a -3 dBFS sinewave at one-fourth the sampling frequency. The clock reference input (not the D/A converter input, if applicable) is driven with a signal whose phase is jittered with a 40 ns p-p sine-wave whose frequency varies from 62.5 Hz to 8 kHz in octave steps. The output spectrum is measured using an FFT at each step and the results overlaid. The peak value of each sideband component generated by its associated jitter frequency (i.e. Measured Frequency below) is reported. The measurements are repeated with a 997 Hz input to the converter. Results are expressed as dBFS for each octave step.</td></tr>
<tr><td>Performance Specification</td><td>12 kHz<table><tr><th>Jitter Frequency</th><th>Measured Frequency</th><th>Measured Limit</th></tr>
<tr><td>8 kHz</td><td>4 kHz</td><td>-120 dBFS</td></tr>
<tr><td>4 kHz</td><td>8 kHz</td><td>-110 dBFS</td></tr>
<tr><td>2 kHz</td><td>10 kHz</td><td>-110 dBFS</td></tr>
<tr><td>1 kHz</td><td>11 kHz</td><td>-110 dBFS</td></tr>
<tr><td>500 Hz</td><td>11.5 kHz</td><td>-100 dBFS</td></tr>
<tr><td>250 Hz</td><td>11.75 kHz</td><td>-85 dBFS</td></tr>
<tr><td>125 Hz</td><td>11. 875 kHz</td><td>-70 dBFS</td></tr>
<tr><td>63 Hz</td><td>11.937 kHz</td><td>-60 dBFS</td></tr>
</table>997 Hz</td></tr>
</table>

[6] Application Note: The FADGI process averaged eight 32k point FFTs using power averaging and utilizes a table sweep to eliminate the harmonic components from being displayed.
[7] See the explanatory note about Alias Rejection in appendix B.

	Jitter Frequency	Measured Frequency	Measured Limit
	500 Hz	497 Hz	-110 dBFS
	250 Hz	747 Hz	-100 dBFS
	125 Hz	872 Hz	-90 dBFS
	63 Hz	934 Hz	-80 dBFS

Test Name	**Jitter Transfer Gain**
Test Method	The converter input is driven with a -3 dBFS sinewave at 997 Hz. The clock reference input shall be driven with a signal whose phase is jittered with a 40 ns p-p sine-wave jitter signal whose frequency varies from 62.5 Hz to 8 kHz in octave steps. The p-p jitter at the output shall be measured at each step and the results shall be graphed. Results shall also report the maximum p-p jitter value in ns.
Performance Specification	**Limit** < 20ns p-p

Appendix A. Definitions and Specifications: High-Quality-Level Testing of ADCs

1. Analyzer Specifications

1.1 Standard Notch Filter

The standard notch filter shall have a quality factor Q of at least 1.2 and not more than 3, where Q is defined as the ratio of the center frequency to the difference between the –3 dB frequencies. Multistage notch filters are acceptable if their combined Q measures within these limits using this definition

1.2 Standard Bandpass Filter

The standard band-pass filter shall conform to the class 1 or class 2 response limits described in IEC 61260-1. The attenuation shall be at least 30 dB one octave away from the filter center frequency, and at least 60 dB three octaves away.

NOTE A filter complying with ANSI S1.11-2004 Class 2 requirements with a bandwidth designator b of 2 (that is, a half-octave filter) easily meets this requirement.

If the EUT is very noisy, certain measurements may benefit from the use of a band-pass filter centered on the test frequency to achieve accurate results. Where such measurements are made using a band-pass filter, this shall be noted.

1.3 Narrow Bandpass Filter

A narrow bandpass filter shall have a bandwidth of at least 1/12 octave or a Q of 17.

1.4 THD + N type Distortion Analyzer Specifications

All total harmonic distortion plus noise (THD + N) type distortion analyzers used for measurements in this standard shall utilize a notch filter having an electrical Q of at least 1 and not more than 5. This value shall be verified by measuring the – 3 dB frequencies and computing the ratio of the center frequency to the difference between the – 3 dB frequencies. Multistage notch filters shall be acceptable if their combined Q measures within these limits using this definition. High-pass or band-pass filters should not be part of the measurement path unless specifically required for the test being performed. While such filters may not respond to harmonics only, to be acceptable they must respond to noise, since distortion products which alias in frequency will appear at inharmonic frequencies.

2. Signal Generator Specifications

2.1 Signal Generator Impedance

Unless otherwise specified, the analog signal generators used for measurements in this standard shall have an output impedance of 50 Ohms or less.

2.2 Frequency Accuracy

Signal generators used for measurements in this standard shall provide control over frequency with an accuracy of at least 0,05 %. Alternatively, the frequency may be measured with a frequency counter and adjusted to be within the required accuracy. The frequency adjustment resolution shall be adequate to produce the frequencies specified in the appropriate test.

3. Equipment-Under-Test (EUT) Settings

3.1 General Equipment Settings

The equipment controls shall be set to their normal operating positions except where noted. The switches and controls of the equipment under test (EUT) shall be consistent for all measurements in this standard.

3.2 Emphasis Settings

If any emphasis is provided, it shall be set to the manufacturer's recommended position. This setting shall be clearly indicated in the specifications. If a recommended position is not stated by the manufacturer, emphasis shall not be used. If desired, some measurements may be repeated with other settings, but measurements so obtained shall be clearly indicated as supplementary and shall be reported in addition to the results of the same tests performed using the recommended position.

3.3 Dither Settings

If a dither is provided, it shall be turned on, and this fact shall be clearly indicated in the specifications. If desired, some measurements may be repeated without dither. Measurements so obtained shall be clearly indicated as supplementary and shall be reported in addition to the results of the same tests performed with dither.

3.4 Limiter and Compression Settings

If selectable limiter or compression circuits are included in the EUT, they shall be disabled. If their effect may be measured with additional tests, the results shall be reported separately.

3.5 Device preconditioning

The device shall be connected under normal operating conditions for the manufacturer-specified preconditioning period prior to any measurements being performed. This condition is intended to allow the device to stabilize. If no preconditioning period is specified by the manufacturer, a 5-min period shall be assumed. Should operational requirement preclude preconditioning, the manufacturer shall so state.

3.6 Power interruption

Should power to the device be interrupted during the measurements, sufficient time shall be allowed for restabilization to occur.

3.7 Clock Reference Settings

The clock reference shall be set to internal for all tests with the exception of Jitter Susceptibility and Jitter Transfer Gain

3.8 External Clock Interface

Where external clocking is utilized (i.e. Jitter Susceptibility and Jitter Transfer Gain), the interface used should be an interface dedicated to clock reference interface as opposed to clocking using an interface used for digital-to-analog conversion.

Appendix B. Explanatory notes for CMRR and Alias Rejection

1. Explanatory note re: CMRR

In an effort to clarify this test the following two figures are provided. The first figure is from a paper authored by Bill Whitlock, titled Design of High-Performance Balanced Audio Interfaces, and found at http://sound.westhost.com/articles/balanced-interfaces.pdf. This signal diagram visualizes the CMRR test method language.

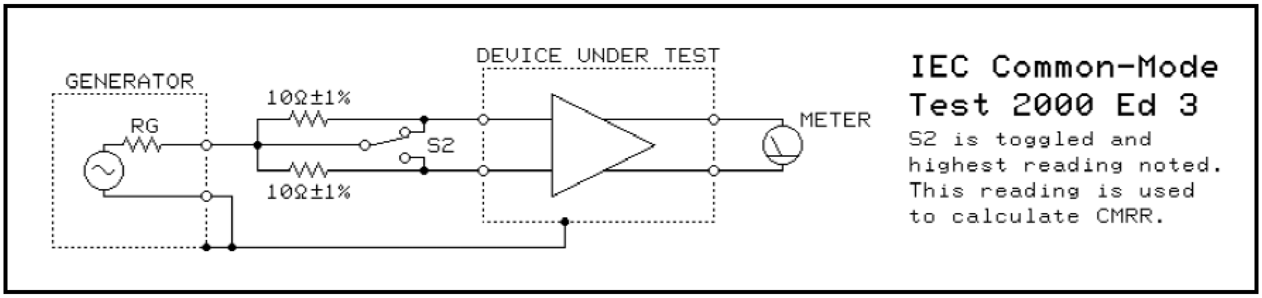

Figure: CMRR test signal diagram

The second figure is a photograph of a box made by Phillip Sztenderowicz. The four momentary-on push-buttons, when pressed, are connected to 600 Ohm and 10 Ohm resistors. This box is placed in between the signal generator and the device under test in order to perform the CMRR test method.

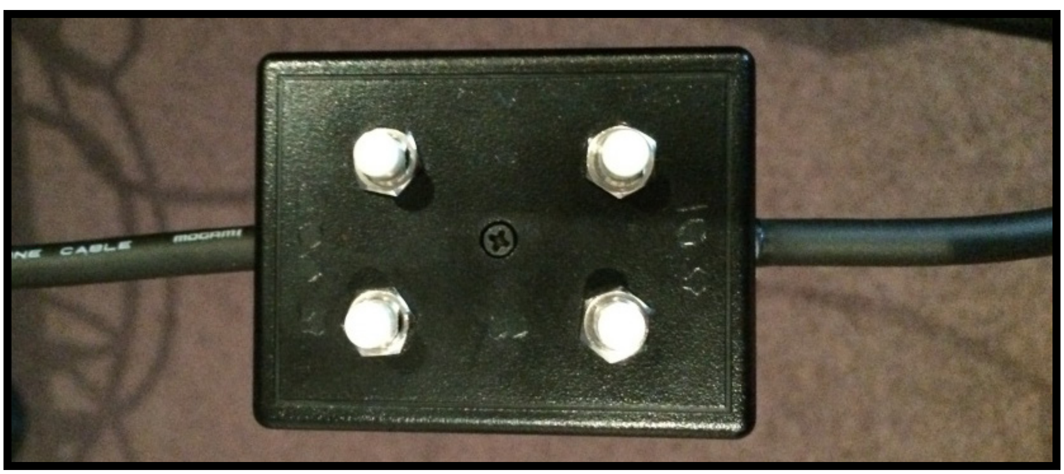

Figure: Box made by Phillip Sztenderowicz to perform CMRR test

2. Explanatory comment re: Alias Rejection

The figure on the next page shows that the calculation is performed by finding the highest aliasing component beyond the initial achievement of alias suppression, and then finding where that matches the sweep that occurs as part of the initial alias suppression. The level is reported as -72 dB and the frequency is reported as 63.1 kHz.

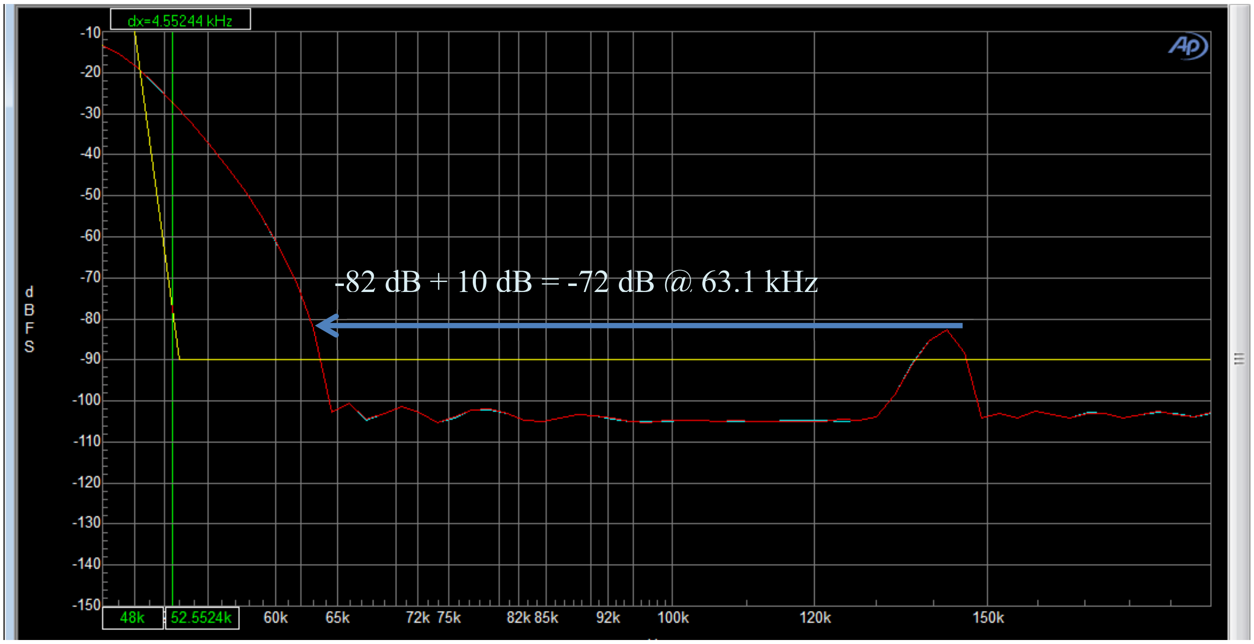

Figure: Explanatory diagram demonstrating measurement of Alias Rejection