PAISANO

Performance Assessment of Instrumentation Systems for Aircraft NOise

[Guidance and Recommendations for Assessment and Validation of Noise Measurement, Recording, and Analysis Instrumentation Systems for Establishing Compliance with Aircraft Noise Certification Specifications and Requirements]

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This document provides guidance in the form of recommendations and requirements applicable to acoustic data collection, recording, and analysis instrumentation systems for use by applicants for aircraft noise certification under the authority of Code of Federal Regulations, Title 14, part 36.

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SI* CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
MASS				

SI* CONVERSION FACTORS

g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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1. Introduction

In accordance with Federal Aviation Administration (FAA) Order 8110.4C: "*Type Certification Process"* (most recently revised as "Change 5", 20 December, 2011V), The U.S. Department of Transportation (USDOT), Office of the Secretary of Transportation (OST), Volpe National Transportation Systems Center ("Volpe") performs audits of aircraft noise certification applicants' instrumentation, software, and methodologies on behalf of FAA's Office of Environment & Energy (AEE), to ensure conformance/compliance to the requirements and specifications of Code of Federal Regulations Title 14 part 36 ("Part 36"). These audits are executed as "validations" of applicants' software, instrumentation, and procedures as applied to aircraft noise certification flight testing.

This document – Performance Assessment of Instrumentation Systems for Aircraft NOise (PAISANO) — is provided as part of the guidance materials developed by Volpe in support of instrumentation validation for aircraft noise certification. It replaces — and is based, in part, on — a previous document developed specifically for guidance on validation of digital audio recording systems, nicknamed "DARP" (Digital Audio Recorder Protocol). This updated version adds guidance for one-third octave band analyzers used in aircraft noise certification. It is applicable to both stand-alone audio recorders and one-third octave band analyzers as well as integrated acoustic data recording and analysis systems (including software-based systems) both commercially available, and those developed in-house by applicants. Provided within are recommendations for interpreting, performing, and reporting performance test results, as well as additional considerations and operational protocols for data acquisition and analysis systems in the context of aircraft noise certification.

It should be noted that validation of instrumentation or analysis software components for one applicant does not universally apply — each applicant should obtain individual validation of their data acquisition and analysis system, as well as their applied use of the system. This includes evaluation of in-house operational protocols and formalized documentation such as a field operator manual or procedural checklist for setup and operation of the instrumentation by the applicant. This may sometimes result in separate validation and reporting efforts for performance characteristics of individual instruments (such as recorders or analyzers) or complete data acquisition and analysis systems, as well as for applicant procedures related to those components and/or systems.

Options for validation of instrumentation systems include:

1. Applicant-performed testing of system functionality and performance characteristics, and submittal of applicant-developed documentation of system performance, setup and operation procedures to Volpe;
2. Third-party (Independent Laboratory) testing of system functionality and performance characteristics, and applicant submittal of performance documentation, as well as applicant-developed documentation of setup and operation procedures to Volpe;
3. System manufacturer testing of functionality and performance characteristics, and applicant

submittal of performance documentation, as well as applicant-developed documentation of setup and operation procedures to Volpe;

4. Physical evaluation of system functionality and performance characteristics directly by Volpe laboratory, combined with applicant-developed documentation of setup and operation procedures;
5. Or some combination of these elements.

Once the validation process is completed, Volpe will generate a validation report to be submitted to FAA/AEE, who will then make an approval determination. The FAA's type certification organization will then send the approval letter to the applicant. The applicant should include such letter from the FAA in each noise certification report. It should be noted that Volpe has no authority to approve applicants' use of instrumentation systems for aircraft noise certification. The guidance provided in this document has been developed from specifications and requirements provided in 14 CFR part 36, Amdt 31 (Part 36); Advisory Circular AC36-4D (the AC); ICAO Annex 16 Volume I, 8th Edition, Amdt 14 (2023) (Annex 16, the Annex); ICAO Environmental Technical Manual Volume I, Doc 9501, Third Edition, Amdt 1(2020) (the ETM); and current FAA Policy.

1.1 Background

Data acquisition and analysis systems for use in aircraft noise certification can take many forms, from a specified combination of individual, standalone, off-the-shelf components, to an entirely custom-built and configured, software-based system.

Commercially available components and systems typically provide substantial flexibility in use, and therefore exhibit complex, sometimes arcane, methods for selecting operational characteristics from available options.

In the past, individual instruments possessed limited functionality, which was reflected in the user interface control scheme: older analog electronics components featured faceplates with individual switches and controls which provided instant visual confirmation of settings, and the level of user-interaction was limited. Contemporary instrumentation elements typically provide setting controls that are implemented in software, often utilizing multi-level menus and multifunction controls – an implementation which tends to obscure the current performance configuration from the operator.

Since some or all of the functions required for such systems can be performed by a computer, and since computers exhibit a wide range of original equipment or aftermarket options for handling audio input signals, there is a need for testing and evaluation in order to establish that the performance is acceptable for noise certification purposes.

Some computer-based systems make use of external standalone DSP (Digital Signal Processing) hardware, or rack-based input modules and analog-to-digital converters. Many come with packaged firmware and software to provide audio recording and analysis functions. Some applicants prefer to design and fabricate their own complete systems, using a combination of custom-sourced hardware and in-house developed software. In some popular systems, manufacturers provide hardware and software development environments; where a combination of manufacturer provided software and user-develop software may be used. And there are still options for legacy type systems assembled from standalone components with individual functionality.

Any combination of such instrumentation may be considered appropriate for use in aircraft noise certification as long as the performance characteristics and user setup and operation procedures meet the current standards defined by the recommendations, specifications, and guidance provided in Part 36, Annex 16, the AC, the ETM, and this guidance document (PAISANO). All instrumentation used for aircraft noise certification must be submitted for approval by FAA.

2. Objectives

This document seeks to inform the aircraft noise certification community with clear and concise guidance and recommendations for verification and validation of data acquisition and analysis systems and end-user procedures intended for use in aircraft noise certification testing in compliance with the regulations and specifications of Part 36, the guidance material provided in the AC, and as incorporated by reference, the standards of Annex 16, and the guidance material provided in the ETM.

Specifically, the objectives of this document are the following:

1) Provide a core set of relevant specifications and methods to evaluate the performance of acoustic data recording devices, one-third octave band analyzers and combined data acquisition and analysis hardware and software systems to be used in aircraft noise certification testing.
2) Provide representative examples of test results, and preferred presentation formats, for the test report.
3) Provide a list of features and operational characteristics that should be considered for reliable field operation.
4) Provide a list of operational protocols and procedural documentation requested for the evaluation.
5) Provide a checklist for the data submittal package.

3. Scope

This document provides procedural guidance for testing and evaluating the performance of acoustic data recorders, one-third octave band analyzers and combined functionality recording and analysis systems intended for use in aircraft noise certification testing. Test results should verify that measured performance characteristics meet the acceptance criteria stated in the applicable standards. Interpretation of performance standards, recommended presentation of test results, and supporting information to be included in the data submittal package are also provided. In addition to such documentation of performance, there is also a requirement is for the applicant to provide documentation of internal setup and operation procedures for the system.

During the audit/validation process described previously, Volpe may determine that additional performance tests or documentation beyond that which is described in this document may be necessary to adequately characterize system performance or operational protocols.

The validation guidance provided herein applies to any acoustic data recorder, one-third octave band analyzer or combined functionality hardware, software or hybrid-based system intended for use in aircraft noise certification testing.

4. Related Standards

Title 14, Combined Federal Regulations, part 36, "Noise Standards: Aircraft Type and Airworthiness Certification", Amendment 31, January 2017 ("Part 36")

International Civil Aviation Organization (ICAO), Annex 16 to the Convention on International Civil Aviation, "Environmental Protection," Volume I, "Aircraft Noise", Amdt 14, July 2023, ("The Annex", "Annex 16")

IEC 61260-1, International Electrotechnical Commission, International Standard, "Electroacoustics – Octave-band and fractional-octave-band filters – Part 1: Specifications," Edition 1.0, April 2014

IEC 61260-2, International Electrotechnical Commission, International Standard, "Electroacoustics – Octave-band and fractional-octave-band filters – Part 2: Pattern Evaluation Tests," Edition 1.1, April 2017

IEC 61260-3, International Electrotechnical Commission, International Standard, "Electroacoustics – Octave-band and fractional-octave-band filters – Part 3: Periodic Tests," Edition 1.0, March 2017

IEC 61265, International Electrotechnical Commission, International Standard, "Electroacoustics – Instruments for Measurement of Aircraft Noise – Performance requirements for systems to measure one-third-octave-band sound pressure levels in noise certification of transport-category aeroplanes", Edition 2.0, May 2018

IEC 61672-1, International Electrotechnical Commission, International Standard, "Electroacoustics – Sound level meters – Part 1: Specifications", Edition 2.0, September 2013

ISO/IEC Guide 98-3, Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM: 2008)

5. Terms and Definitions

Definitions for additional terms can be found in clause 3 of IEC 61260-1 (2014) and clause 3 of IEC 61265 (2018).

5.1 acceptance limit

specified upper or lower bound of permissible measured quantity values

5.2 alias (artifact)

spurious spectral component resulting from the process of converting an analog signal to its digital representation. Occurs when the frequency of any component of the input analog signal is greater than one-half of the digital sampling frequency. Such aliases or artifacts can appear in the frequency bandwidth of interest, potentially contaminating or obscuring the signal of interest.

5.3 anti-alias filter

Lowpass filter to limit the bandwidth of the input signal prior to digitization or re-digitization by removing, or substantially attenuating, undesired frequency components. Anti-aliasing filters can be analog, digital, or a combination, but there must be at the very least, a simple analog filter at the input to limit out-of-band signals from being digitized.

5.4 bandedge frequencies

frequencies at the lower and upper edges of the passband of a bandpass filter such that the exact midband frequency is the geometric mean of the lower and upper bandedge frequencies

5.5 bandpass filter

filter with a single transmission band (or passband with small relative attenuation) extending from a lower bandedge frequency greater than zero to a finite upper bandedge frequency

5.6 bit

abbreviation for binary digit, represented by a 0 or a 1

5.7 bit depth

the number of bits of digital audio information recorded for each sample of a continuous signal

NOTE: Bit depth determines the resolution of a sample in a set of digital audio data. Increasing the bit depth permits resolution of smaller fluctuations of an audio signal. Bit depth also has a strong influence on the extent of linear operating range.

5.8 bit rate

number of bits of discrete data processed per second by a digital signal-processing system

NOTE: For a measurement system that includes a digital audio recording device, bit rate equals the product of (bit depth) times (sampling frequency) times (number of channels used for recording). As an example, for a bit depth of 16 bits per sample, a sampling frequency of 44000 samples per second, and a single channel, the bit rate is 704 kbits/s.

5.9 calibration check frequency

nominal frequency of the sinusoidal sound pressure signal produced by a sound calibrator used to establish acoustical level sensitivity of the measurement system

NOTE: Calibration check frequency is expressed in hertz (Hz).

5.10 calibration sound pressure level

sound pressure level produced in the cavity of the coupler of the sound calibrator used to establish the overall acoustical sensitivity of a measurement system at a calibration check frequency

NOTE: Calibration sound pressure level is expressed in decibels relative to the standard reference value of 20 µPa, commonly notated as dBSPL.

5.11 device under test (DUT)

generic term referring to the device that is the subject of test and evaluation procedures

5.12 effective bandwidth

in Hertz, the equivalent passband width of a bandpass filter, based on the energy under the filter response curve and compared to that for a range of frequencies where there is no attenuation for a notional "ideal" (rectangular) bandpass filter. See Section 8.3.3 of this document for additional info.

5.13 exact midband frequency

frequency that has a specified relationship to the reference frequency such that the ratio of the exact midband frequencies of any two contiguous bandpass filters is the same for all filters in a filter set of a specified bandwidth

5.14 filter attenuation

at any frequency, for a bandpass filter, the input signal level in decibels minus the corresponding output signal level

5.15 level linearity

level linearity is a measure of amplitude accuracy over a dynamic range. It is characterized by the difference between a measured output signal level and the corresponding expected output signal level

5.16 level range

range of nominal input signal levels, expressed in dB, extending from a lower boundary to an upper boundary as determined by the setting of input level controls on a recording device

5.17 linear operating range

on any level range and at a stated frequency, range of steady sinusoidal electrical input signal levels over which level linearity errors do not exceed the applicable tolerance limits and extending from a nominal lower boundary to a nominal upper boundary

NOTE 1: Boundaries as well as the extent of a linear operating range are expressed in decibels (dB).

NOTE 2: The upper boundary of a linear operating range may be superseded by the onset of an overload condition. For example, $1\%\ THD + N$ may be reached prior to the exceedance of the applicable tolerance limit for level linearity errors

5.18 microphone system

components of a measurement system that produce an electrical output signal in response to a sound pressure input signal and generally include a microphone, preamplifier, power supply, cables, and other devices as necessary

5.19 nominal midband frequency

rounded midband frequency for the designation of bandpass filters, expressed in Hz

5.20 normalized effective bandwidth

for a bandpass filter, the ratio of the effective bandwidth (defined in 5.12) of a filter relative to the geometric center frequency of that filter

5.21 normalized frequency

for a bandpass filter, ratio of any frequency to the corresponding exact midband frequency

5.22 normalized reference effective bandwidth

normalized effective bandwidth (defined in 5.20) for an “ideal” (rectangular) bandpass filter having zero relative attenuation in the passband and infinite relative attenuation at other frequencies. For a one-third octave band filter, the normalized reference effective bandwidth is 0.230259 (“23 percent”).

5.23 notch filter

band-reject filter designed to remove a particular narrow range of frequencies from a broadband signal

5.24 Nyquist frequency

also called folding frequency. For the purposes of this document, it is defined as half the sampling frequency at which discrete digital samples are obtained from a continuous analog input signal. The Nyquist frequency also represents the highest frequency component of an analog input signal that can be sampled and reconstructed without aliasing.

NOTE: The term Nyquist Frequency has acquired several independent usages in sampling theory, and care should be taken to define the particular usage that applies in a particular document. For the purposes of PAISANO, the Nyquist frequency equals 0.5 times the sampling frequency, and is used interchangeably with the term folding frequency.

5.25 overload

describes a condition where the level of an analog input signal exceeds the capability of an analog-to-digital converter to detect further increases in input voltage. It is characterized by a sharp rise in distortion and is commonly associated with $1\,\%\,\mathrm{THD}+\mathrm{N}$

5.26 quality factor (Q)

also referred to as Q factor. Defined as the ratio of the midband frequency of a filter divided by the bandwidth of the filter at the frequencies where attenuation equals 3 dB (half-power points). Derived by the following expression: $Q = f_c/(f_h - f_l)$, where f_c is the nominal midband frequency of a filter, f_h is the upper −3 dB point, and f_l is the lower −3 dB point.

For example, if a filter has a nominal midband frequency of 1000 Hz and exhibits 3 dB attenuation at 800 Hz and 1250 Hz, then $Q = 1000 / (1250 - 800) = 2.2$

5.27 reference attenuation

for all bandpass filters in an instrument or system, nominal filter attenuation, expressed in dB, in the passband for determining relative attenuation

5.28 reference frequency

single frequency selected to normalize the attenuation response for all bandpass filters in a filter set. For the purpose of this validation, the reference frequency is 1000 Hz

5.29 reference level range

level range used for determining the acoustical sensitivity of a measurement system and containing the calibration sound pressure level

5.30 relative attenuation

filter attenuation minus the reference attenuation

5.31 sampling frequency

also called sample rate. Number of samples per second taken from a continuous signal to form a digital reconstruction of the original signal.

5.32 time-invariant operation

operational mode or capability of a system of band-pass filters such that the response to a signal is independent of the time when the signal was applied

5.33 total harmonic distortion plus noise (THD + N)

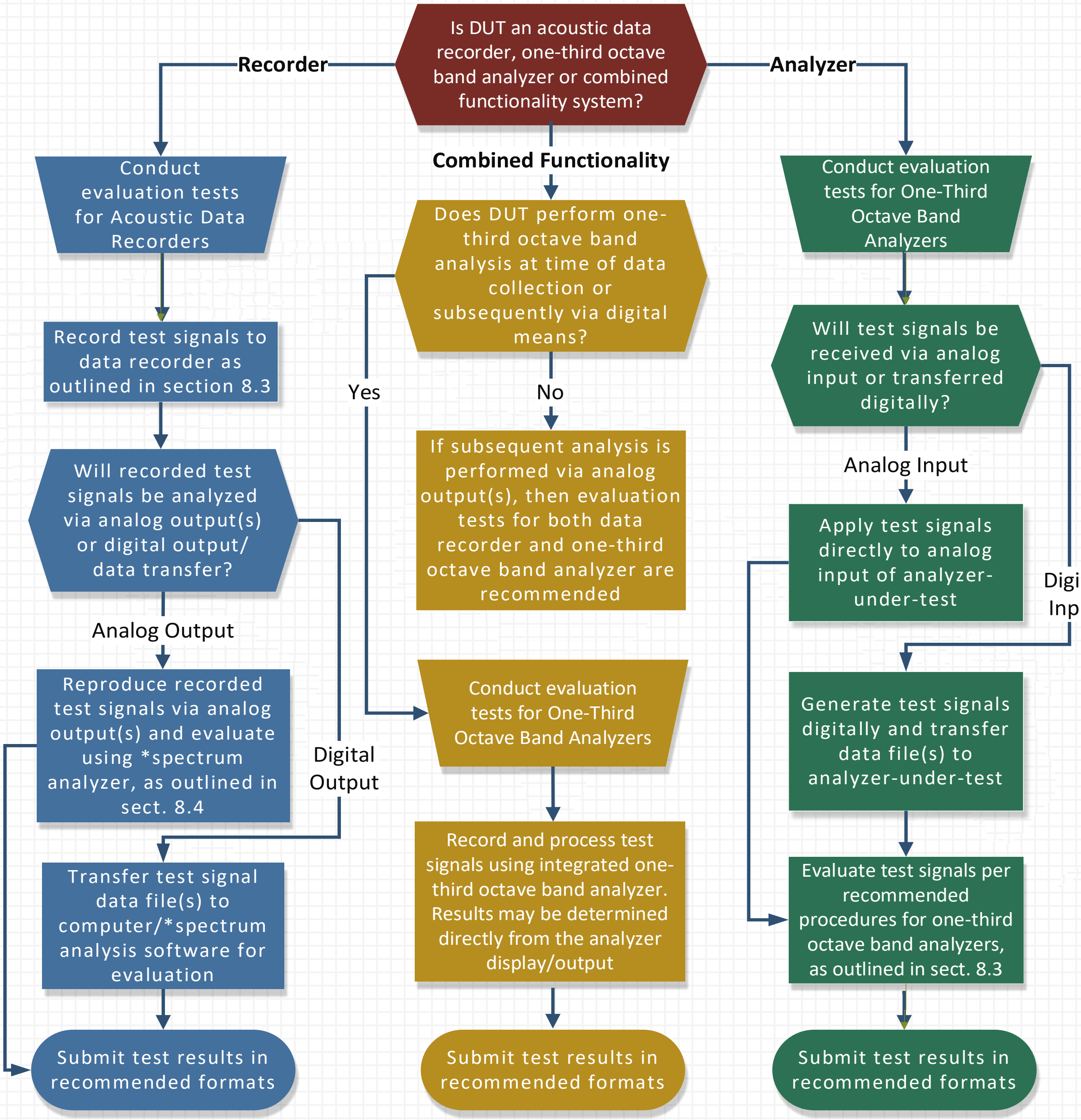
for a given sinusoidal input signal, ratio of the root-mean-square output signal with the fundamental component of the input signal removed to the root-mean-square of the output signal with the fundamental component present.

NOTE: THD + N is expressed as a percentage and may be calculated from the difference between the levels, in decibels, of the two output signals. The bandwidth of the measurement device should always be stated.

6. Device-Under-Test

The device-under-test (DUT) may be a one-third octave band analyzer, acoustic data recorder or system encompassing both functionalities that is intended for use in aircraft noise certification testing. A combined functionality system may consist of discrete components or may be contained within a single component. The device(s) or system may be analog or digital in nature, and may comprise hardware, software, or a combination of the two.

The capabilities inherent in the DUT, as well as certain operational protocols, will determine which of the evaluation tests should be performed and included in the test report. Generally, if the DUT is strictly used as a one-third octave band analyzer or acoustic data recorder, or consists of discrete components used for each purpose, then perform the evaluation tests contained in the corresponding section(s) of this guidance for each. If the DUT combines acoustic data recording and one-third octave band analysis and the analysis is performed at the time of data collection, then perform testing associated with one-third octave band analyzers. If, however, recorded data is subsequently played back via analog output(s) for analysis, then all tests from section 8 are recommended. In the event that certain tests may not be possible, such as when a specific capability does not exist or cannot be isolated from other functionalities, then the limitation should be stated in the test report. A flowchart for the applicability of evaluation tests for various DUT configurations and protocols is provided in figure 1.



*Any one-third octave band analyzer or acoustic data recorder that is used for aircraft noise certification testing should be evaluated according to the corresponding guidance provided in this document

Figure 1. Recommended test path for aircraft noise certification instrumentation

7. Test equipment and conditions

7.1 Test Instruments

It is recommended that the laboratory where the testing of recording and/or analysis systems is performed use instruments with valid calibrations for the appropriate quantities. The calibrations should be traceable to national standards, as recommended. Most of the test procedures utilize steady sinusoidal signals of various frequencies and signal levels. Sinusoidal signals used for the testing of filter attenuation should have a total distortion of not more than 0.01 % for class 1 filters. The total distortion for sinusoidal signals for other tests should not exceed 0.1 %. Instruments for measuring the environmental conditions during the tests should have an expanded uncertainty not exceeding 0.5 °C for temperature and 3 % for humidity.

For bandpass filters that are incorporated into sound level meters, the display indicator of the device may be used to measure the level of the output signal from the filter set, if the display is the primary means of determining measured levels. For filter sets where the output is stored internally or provided as an output that is available in a manufacturer-specified digital format (for example over a digital interface connection), the level of the output should be determined from the stored or digital output to a suitable display. Where multiple outputs are present, if an output is specified in the instruction manual for testing, this output should be used for the evaluation tests. For bandpass filters that operate as components of computer-based systems or combined hardware & software systems, a user interface (UI) may be used to determine the output signal level.

7.1.1 Instrument configuration

1. All hardware configurations used during testing should be documented with a diagram in the test report. Appropriate labeling with specific make and model of the test instruments should be included.
2. If software is used, please provide name of software, developer, and version/revision numbers.
3. If signal input or output adapters, or cable modifications, are required for DUT interface, consult with the DUT instruction manual or with the manufacturer for recommended wiring and pin assignments, e.g., when interfacing balanced and unbalanced audio connections.

7.1.2 Uncertainty related to test instruments

Actual measurement uncertainties should be calculated for a coverage probability of 95 %. Calculation of the actual measurement uncertainty for a particular test should consider at least the following components, as applicable[1]:

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[1] ISO/IEC Guide 98-3, Uncertainty of measurement, Part 3 (GUM:2008)

1. The uncertainty attributed to calibration of the individual instruments and equipment used to perform the test;
2. The uncertainty resulting from environmental effects;
3. The uncertainty resulting from errors that may be present in the applied signals;
4. The uncertainty attributed to effects associated with the repeatability of the results of the measurements. When a laboratory is only advised to perform a single measurement, it is necessary for the laboratory to make an estimate of the contribution of random effects to the total uncertainty. The estimate should be determined from an evaluation of several measurement results previously obtained for a similar filter and parameter;
5. The uncertainty associated with the resolution of the display device used to display the response from the DUT. For digital display devices that indicate signal levels with a resolution of 0.1 dB, the uncertainty component should be taken as a rectangular distribution with semi-range of 0.05 dB.
6. Conformance to the specifications is demonstrated when (a) the measured deviations from the evaluation tests do not exceed the applicable acceptance limits and (b) the corresponding actual expanded uncertainties of measurements does not exceed the corresponding maximum-permitted uncertainty of measurement given in IEC 61260-1 (2014), Annex B.

7.2 Environmental Conditions for Testing

Evaluation tests should be performed in an environmentally controlled setting. Environmental conditions at the time of conducting evaluation tests should be measured and the results included in the test report. In the event that a given test result is at or very near any of the stated acceptance limits, this information may be referenced against manufacturer supplied environmental specifications.

The following recommended environmental conditions are expanded around the internationally standardized reference environmental conditions for specifying the performance of a measurement system, as stated in IEC 61625 (2018), 61260-1 (2014):

Table 1. Environmental conditions for evaluation testing

	IEC 61625 (2018), 61260-1 (2014)	Nominal
Air temperature	10 °C to 30 °C	23 °C
Static air pressure	80 kPa to 105 kPa	101.325 kPa
Relative humidity	30 % to 75 %	50 %

8. Evaluation Tests

The following tests and procedures have been designed to verify and validate relevant performance characteristics of measurement/recording/analysis systems and components to be used in aircraft noise certification testing.

For each test, the following is provided:
1) an objective;
2) applicable performance specifications;
3) recommended step-by-step test procedures: and
4) instructions, with examples, for test-result presentation.

8.1 General guidance for testing – all systems

1. Instrument settings should be documented and included in the test report. Specific settings available to the user will vary with DUT, and examples of instrument settings can include sampling rate, input range, signal gain, signal conditioning, data storage interval, time averaging, or any other parameter that affects data. Because DUT performance is dependent on device settings, validation tests should be conducted with settings anticipated for typical use during aircraft noise certification testing. Device settings should remain consistent throughout all validation tests. Any changes from the initial settings should be documented, explained, and included in the test report.
2. Validation tests should be conducted on each input channel intended for use in aircraft noise certification testing.
3. Since most of the performance specifications cited in this document were written at a time when discrete hardware devices were typically used for recording/playback and one-third octave band analysis, test procedures reflect this assumption. However, when testing integrated recorder/one-third octave band analysis systems, test signal analysis may occur directly in the system software. That is, once captured, the test signal may remain in the digital domain, and it is not required to playback a recorded test signal to an external signal analyzer. Additionally;
4. For integrated recorder/one-third octave band analysis systems or software-based spectrum analyzers, the level of filter output(s) should be determined from a user interface or from values saved to file within the software. For filter sets with digital readout devices, or with output that is available in a manufacturer-specified digital format (for example over a digital interface connection), the level of the output should be determined from the numeric readout or via the digital output to a suitable display or recording device.
5. If an applicant is unable to undertake or to complete the validation tests due to limitations of available test instruments or time constraints, Volpe recommends that the applicant obtain the services of a third-party test facility. Results from any third-party test facility should adhere to the protocol in this document and should be clearly identified in the test report.

6. Acceptance limits in this standard include allowances for deviations due to design, manufacturing, and aging. Acceptance limits are provided for allowable values of measured deviations from design goals. Conformance to a specification is established when measured deviations from design goals do not exceed the corresponding acceptance limits and the uncertainty of measurement does not exceed the corresponding maximum-permitted uncertainty of measurement for a coverage probability of 95 %.
7. After completion of the validation tests, the applicant should prepare a functionality and performance test report and submit to the Volpe Center Environmental Measurement and Modeling Division. The test report may be submitted separately or included as part of a larger Certification Validation Package. Additional information and guidance can be found on the Volpe Aircraft Noise Certification Support web portal at: https://www.volpe.dot.gov/environmental-energy-systems/environmental-measurement-and-modeling/AC-Cert

   All questions should be referred to: David.Read@dot.gov and Chris.Cutler-Wood@dot.gov

8.1.1 Establish reference level

8.1.1.1 Objective

Set the reference level range, if applicable, and establish the starting point for use in performance evaluation tests.

8.1.1.2 Performance Specification

No performance specification is needed.

8.1.1.3 Test Guidance

1. Apply a sound level calibrator to a certification-compliant microphone system.
2. Connect the microphone system to the analog input of the DUT.
3. Adjust the DUT level-range-control to record the calibration signal while allowing for additional operating range.

NOTE: Linear operating range, above the calibration level, acts as a safety buffer from accidental overload. It is recommended that this level be set conservatively based on the highest anticipated level that will be recorded during use.

4. Record the signal to the DUT for 30 seconds.
5. If applicable, play back the recorded acoustic calibration signal to a one-third octave band spectrum analyzer. Otherwise, use the DUT's integrated analyzer to determine the 10-second averaged level of the recorded signal in the one-third octave band that contains the calibration

check frequency, typically 1000 Hz or 250 Hz. The 10-second averaged level indicated by the spectrum analyzer establishes the starting point on the reference level range at the calibration check frequency for the acoustic input signal. The starting point on the reference level range should be identified by the nominal calibration sound pressure level, e.g., by 94, 114, or 124 dBSPL.

6. Replace the sound calibrator and microphone system with a sinusoidal signal generator and apply to the analog input of the DUT. Set the frequency of the generator to the nominal frequency of the sound calibrator. Adjust the signal generator to produce a signal level that is approximately the same as the level of the signal from the sound calibrator and record the signal on the DUT for 30 seconds. If applicable, play back the recorded signal to a spectrum analyzer and note the indicated 10-second averaged output level. If the DUT is a combined functionality system, playback is not needed as this level may be determined directly from the integrated one-third octave band analyzer.
7. Iteratively adjust the signal generator level that is being input to the DUT until the indicated 10-second averaged output level is within 0.1 dB of the level previously noted for the sound calibrator signal. Document the settings of the signal generator and, if applicable, the step attenuator that yielded the desired output signal level. These settings establish the starting point on the reference level range for electrical input signals. Starting point settings should be documented on a manual log or by software and included in the test report.

8.2 One-Third Octave Band Analyzer Performance Tests

The following guidance and procedures are recommended for the evaluation of one-third octave band analyzers intended for use in aircraft noise certification. The methods described are based largely on pattern-evaluation tests as defined in IEC 61260-2 (2017) and periodic tests as defined in IEC 61260-3 (2017). An equivalent procedure approved by the certificating authority is also acceptable. Additional testing and verification of functionalities, as presented in this document, is highly recommended.

The test procedures assume the device-under-test to employ base-10 filter design, however base-2 designs will also be considered. The certificating authority may allow the substitution of an analysis system that complies with class 2 performance requirements of IEC 61260-1 (2014) or with class 1 or class 2 of an earlier version of IEC 61260.

8.2.1 Level linearity

8.2.1.1 Objective

To quantify the level linearity deviation, for each available level range, at specified exact midband frequencies within a one-third octave band filter set. Level linearity deviation is zero at the reference input signal level on the reference level range and is determined by calculating the measured output signal level minus the expected output signal level.

8.2.1.2 Performance Specification

As defined in IEC 61260-1 (2014), section 5.13, for all filter bandwidths, and for each available level range, the linear operating range at the exact midband frequency of a filter should be at least 60 dB for class 1 filters. For input signal levels from the upper boundary of the linear operating range to 40 dB less than the upper boundary, the acceptance limits for the level linearity deviation are ±0.5 dB for class 1 filters. For input signal levels from 40 dB less than the upper boundary to the lower boundary of the linear operating range, the acceptance limits for the level linearity deviation should not exceed ±0.7 dB for class 1 filters.

8.2.1.3 Test Guidance

Level linearity should be tested for at least three filters on each available level range.

1. On the reference level range, level linearity testing should be performed at the exact midband frequencies corresponding to the lowest and highest filters within the filter set, as well as an exact midband frequency in the middle of the frequency range, preferably at 1 kHz. If the lowest and highest midband frequencies in the filter set are beyond the extent of the 50 Hz to 10 kHz bandwidth of interest, it is recommended that additional tests be performed at 50.119 Hz and 10 kHz.
2. At each test frequency and for any level range, level linearity deviation is determined from the measured (output) signal level minus the expected (output) signal level.

NOTE: Changes in the level of the input signal may be determined from changes to the setting of the signal generator or input signal attenuator. Accuracy of intended level changes may be confirmed via direct measurement of the test signal by the one-third octave band spectrum analyzer.

3. At a selected test frequency, tests of level linearity begin at the starting point on the reference level range as determined in section 8.2. Capture the sinusoidal input signal to the DUT. Note the 10-second averaged output signal level as indicated by the spectrum analyzer display. Level linearity error is zero at the starting point on the reference level range. All test measurements are referenced to the starting point.
4. The procedure in item (3) is repeated with the level of the input signal increased above the starting point in steps no greater than 5 dB up to and preferably beyond the indication of overload, and then down from the starting point to the first indication of under-range (if provided) and into the region where self-generated noise causes substantial level-linearity errors. An overload indication should not occur prior to the stated upper boundary of the level range. Once within 5 dB of the upper boundary and lower boundaries, steps of 1 dB should be used. When approaching the lower boundary of the operating range, the averaging time during a measurement may be extended to establish a stable indication as the influence of internally generated noise will increase.

NOTE: Increments or decrements in the level of the input signal may need to be less than 1 dB in the regions near the upper and the lower boundary of the linear operating range to provide adequate resolution of the results.

NOTE 2: Level-linearity tests at input signal levels up to 5 dB greater than the upper boundary, or down to 5 dB less than the lower boundary, of the linear operating range are recommended so that the degradation of linearity characteristics may be documented.

NOTE 3: Some digital audio recording devices may provide an indication of, or reference to, "0 dB," "full-scale," or "digital full-scale." These indications should not be confused with the upper boundary of the linear operating range.

5. For each test frequency, tabulate the expected signal level for a given input signal level, the corresponding measured signal level as indicated by the one-third octave band spectrum analyzer, and the level-linearity deviation. Steps 3, 4, and 5 should be repeated for all test frequencies.
6. The entire test sequence should be repeated for any addition level range that may be used for aircraft noise certification testing.

8.2.1.4 Results

It is recommended that all test data be presented in tabular format. For all level ranges tested, provide a separate table for each exact midband frequency evaluated and state the upper and lower boundaries of the operating range as specified in the operator's manual, then fill in the test information as determined from the procedures described in section 8.3.1.3. Table 2 provides a partial results example outlining the recommended format and showing data from the starting point on the reference level range to the upper limit of the linear operating range.

Table 2. Example results format for presenting level linearity deviation for one-third-octave band filters

Level Range: Reference level range			
Exact midband frequency (Hz): 1000			
Upper boundary (dB): 115		Lower boundary (dB): 15	
Input level (dB)	**Expected signal level (dB)**	**Measured signal level (dB)**	**Level linearity deviation (± dB)**
94.00 (ref)	94.00	94.02	*Zero @ starting point on Ref level range
14.00	14.02	14.77	0.75
15.00	15.02	15.62	0.60
16.00	16.02	16.5	0.48
17.00	17.02	17.4	0.38

18.00	18.02	18.32	0.30
19.00	19.02	19.26	0.24
20.00	20.02	20.2	0.18
25.00	25.02	25.06	0.04
30.00	30.02	30.02	0.00
35.00	35.02	35.01	−0.01
40.00	40.02	40.00	−0.02
50.00	50.02	50.00	−0.02
60.00	60.02	60.00	−0.02
70.00	70.02	70.00	−0.02
80.00	80.02	80.00	−0.02
90.00	90.02	90.00	−0.02
95.00	95.02	95.00	−0.02
100.00	100.02	100.00	−0.02
105.00	105.02	105.00	−0.02
110.00	110.02	110.00	−0.02
111.00	111.02	111.00	−0.02
112.00	112.02	112.00	−0.02
113.00	113.02	113.00	−0.02
114.00	114.02	113.81	−0.21
115.00	115.02	114.52	−0.50
116.00	116.02	115.18	−0.84

8.2.2 Relative attenuation (filter response shape)

8.2.2.1 Objective

To determine the attenuation characteristics and thus, the filter response for each filter within a set of one-third octave band filters. To accomplish this, characterize the ratio of the peak output voltage to the corresponding test signal voltage for a range of frequencies spanning from 0.5 times the exact midband frequency of the filter in the set with the lowest midband frequency, to 1.5 times the midband frequency of the filter in the set with the highest midband frequency.

8.2.2.2 Performance Specification

As demonstrated in IEC 61260-1 (2014), Annex F, the acceptance limits are dependent on the relationship of the test frequency f to the exact midband frequency f_m of the filter passband under test. Table 2 presents the acceptance limits for one-third octave band filter response and Table 3 presents corresponding test frequencies and acceptance criteria where $f_m =$ 1 kHz.

NOTE: Historically, one-third octave band filter shapes used in analyzers for aircraft noise certification were of the Butterworth design, providing a maximally-flat passband, and smoothly varying response in the transition bands. Current specifications allow for infinite attenuation of response in the transition bands, which allows for filter designs more closely approximating an "ideal" rectangular filter shape. Note that FAA policy recommends use of 3rd Order Butterworth designs but allows for other designs if it can be demonstrated that results would not be substantially different from those obtained using the Butterworth design.

Table 3. General acceptance criteria for one-third-octave band filter response

Normalized frequency $\Omega = f/f_m$		**Minimum; maximum acceptance limits on relative attenuation (dB)**	
		Class 1	**Class 2**
$\Omega_{l(1/3)}$	< 0.18546	$+70; +\infty$	$+60; +\infty$
$\Omega_{l(1/3)}$	0.32748	$+60; +\infty$	$+54; +\infty$
$\Omega_{l(1/3)}$	0.53143	$+40.5; +\infty$	$+39.5; +\infty$
$\Omega_{l(1/3)}$	0.77257	$+16.6; +\infty$	$+15.6; +\infty$
$\Omega_{1(1/3)} - \varepsilon^*$	$0.89125 - \varepsilon$	$+1.2; +\infty$	$+0.8; +\infty$
$\Omega_{1(1/3)} + \varepsilon^*$	$0.89125 + \varepsilon$	$-0.4; +5.3$	$-0.6; +5.8$
$\Omega_{l(1/3)}$	0.91958	$-0.4; +1.4$	$-0.6; +1.7$
$\Omega_{l(1/3)}$	0.94719	$-0.4; +0.7$	$-0.6; +0.9$
$\Omega_{l(1/3)}$	0.97402	$-0.4; +0.5$	$-0.6; +0.7$
$\Omega_{l(1/3)}$⍰⍰ $\Omega_{h(1/3)}$	1.00000	$-0.4; +0.4$	$-0.6; +0.6$
$\Omega_{h(1/3)}$	1.02667	$-0.4; +0.5$	$-0.6; +0.7$
$\Omega_{h(1/3)}$	1.05575	$-0.4; +0.7$	$-0.6; +0.9$
$\Omega_{h(1/3)}$	1.08746	$-0.4; +1.4$	$-0.6; +1.7$
$\Omega_{2(1/3)} - \varepsilon^*$	$1.12202 - \varepsilon$	$-0.4; +5.3$	$-0.6; +5.8$
$\Omega_{2(1/3)} + \varepsilon^*$	$1.12202 + \varepsilon$	$+1.2; +\infty$	$+0.8; +\infty$
$\Omega_{h(1/3)}$	1.29437	$+16.6; +\infty$	$+15.6; +\infty$
$\Omega_{h(1/3)}$	1.88173	$+40.5; +\infty$	$+39.5; +\infty$
$\Omega_{h(1/3)}$	3.05365	$+60; +\infty$	$+54; +\infty$
$\Omega_{h(1/3)}$	> 5.39195	$+70; +\infty$	$+60; +\infty$

* ε is any small number approaching zero in the regions around the lower and upper normalized bandedge frequencies

Table 3. Example one-third octave-band filter response acceptance criteria for a class 1 filter with $f_m = 1$ kHz

Test frequency (Hz)	Minimum; maximum acceptance limits on relative attenuation (dB)
185.5	$+70; +\infty$
327.5	$+60; +\infty$
531.4	$+40.5; +\infty$
772.6	$+16.6; +\infty$
890.3	$+1.2; +\infty$
892.3	$-0.4; +5.3$
919.6	$-0.4; +1.4$
947.2	$-0.4; +0.7$
974.0	$-0.4; +0.5$
1000.0	$-0.4; +0.4$
1026.7	$-0.4; +0.5$
1055.8	$-0.4; +0.7$
1087.5	$-0.4; +1.4$
1121.0	$-0.4; +5.3$
1123.0	$+1.2; +\infty$
1294.4	$+16.6; +\infty$
1881.7	$+40.5; +\infty$
3053.7	$+60; +\infty$
5392.0	$+70; +\infty$

8.2.2.3 Test Guidance

NOTE: the measurement of relative attenuation and summation of output signals may be made by the same set of measurements using the response to constant amplitude sinusoidal signals at various frequencies as determined below.

1. On the reference level range, apply a steady sinusoidal signal to the analog input of the DUT.
2. Adjust the input signal level to be $1\ (\pm 0.1)$ dB below the upper limit of the linear operating range.
3. The frequencies of the sinusoidal input signals are dependent on the filter under test and are spaced at equal intervals on a logarithmic scale centered on the exact midband frequency.

Specific test frequencies may be derived from the following expression as presented in IEC 61260-2 (2017), section 7.2.1.4:

If S is the number of test frequencies per filter bandwidth, the normalized frequency Ω_i of the i-th test signal is determined from:

$$\Omega_i = G^{\frac{i}{b \cdot S}}$$

Where:

i is a positive or negative integer, including zero. G and b are the octave frequency ratio and the inverse of the bandwidth designator.

4. It is recommended to examine all filters covering the nominal range of center frequencies from at least 50 Hz to 10 kHz inclusive.
5. The overall frequency range of testing should start from 0.5 times the exact midband frequency of the filter in the set with the lowest midband frequency and extend to 1.5 times the midband frequency of the filter in the set with the highest midband frequency. An example set of test frequencies for a 1 kHz filter and the corresponding acceptance limits are given in Table 3.
6. Capture and store at least a 30-second sample of the signal, and note the output level.
7. Relative attenuation, $\Delta A(\Omega)$ at normalized frequency, $\Omega = f/f_m$, determined from the following expression:

$$\Delta A(\Omega) = A(\Omega) - A_{\mathrm{ref}}$$

Where:

A_{ref} is the reference attenuation as indicated in the filter specifications provided by the manufacturer. Resolution to the hundredth of a decibel is recommended for reporting the measurements of output signal levels.

NOTE: If the filter consists of a set of filters operating concurrently (real-time operation), it will normally be suitable to measure the response to a particular frequency for all filter bands simultaneously and store the result for further calculations.

8.2.2.4 Results

It is recommended that the results for relative attenuation be presented in both tabular and graphic formats for each filter tested. Each table should state the midband frequency of the filter under test, the reference attenuation as indicated in the filter documentation, the signal input level, and the exact frequency of each input signal and the corresponding output signal level as determined in section 8.3.2.3, step 7. Numerical values should be presented with sufficient resolution to determine whether measured values fall within acceptance limit criteria. Table 4 provides an example set of results for a filter with $f_m = 1$ kHz, a reference attenuation of −0.05 dB and an input signal level of 100 dB.

Additionally, graphical presentations of the relative attenuation data are recommended. For evaluation purposes, it is advantageous to present two plots per filter tested; one illustrating the full range of test frequencies and attenuation, as exemplified in Figure 2, and a higher resolution plot presenting the top 5 – 10 dB of attenuation relative to the filter midband frequency, as given in Figure 3. The plots should contain relative attenuation plotted as a function of test frequency, and the figure caption or title should state the filter midband frequency and input signal level. It is also useful to plot the acceptance criteria for comparison, as illustrated in figures 2 and 3.

Table 4. Example results for a relative attenuation test (f_m = 1 kHz, reference attenuation = –0.05 dB, input signal level = 100 dB)

Normalized frequency $\Omega = f/f_m$	Measured Output (dB)	Measured relative attenuation (*filter attenuation minus ref. attenuation*) (dB)	Lower acceptance limit (dB)	Upper acceptance limit (dB)
180.5	1.65	98.35	+70	+∞
327.5	13.81	86.19	+60	+∞
531.4	37.75	62.25	+40.5	+∞
772.6	70.77	29.23	+16.6	+∞
890.3	96.34	3.66	+1.2	+∞
892.3	96.71	3.29	−0.40	+5.3
919.6	99.60	0.40	−0.40	+1.4
947.2	99.99	0.01	−0.40	+0.7
974.0	100.00	0.00	−0.40	+0.5
1000.0	100.00	0.00	−0.40	+0.4
1026.7	100.00	0.00	−0.40	+0.5
1055.8	99.99	0.01	−0.40	+0.7
1087.5	99.60	0.40	−0.40	+1.4
1121.0	96.67	3.33	−0.40	+5.3
1123.0	96.37	3.63	+1.2	+∞
1294.4	70.72	29.28	+16.6	+∞
1881.7	37.62	62.38	+40.5	+∞

3053.7	13.15	86.85	+60	+∞
5397.0	−0.13	100.13	+70	+∞

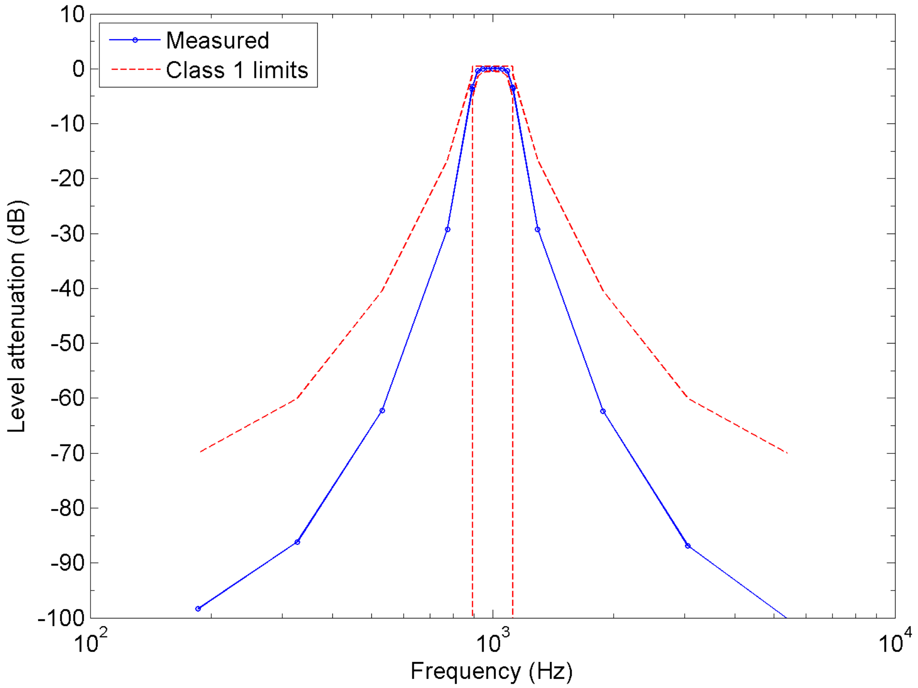

Figure 2. Example of measured relative attenuation for a one-third-octave band filter with $f_m = 1$ kHz, input signal level = 100 dB

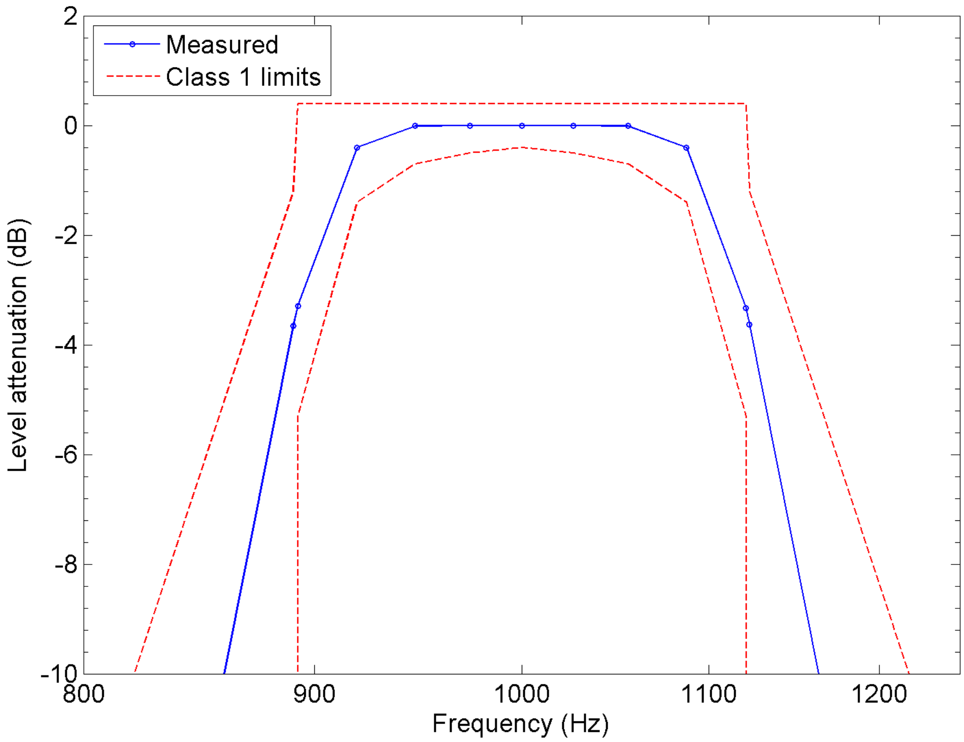

Figure 3. Detail view of relative attenuation illustrating 10 dB down from upper limit of passband for a one-third octave band filter with $f_m = 1$ kHz, input signal level = 100 dB

8.2.3 Filter integrated response (Effective bandwidth)

8.2.3.1 Objective

Examine the frequency range between lower and upper bandedge frequencies for a set of one-third octave passband filter(s). By integrating the filter response over a range of frequencies to obtain the effective bandwidth and comparing against reference bandwidth for an ideal one-third octave band filter, quantify the effective bandwidth deviation of the filter(s) under test.

The requirements for normalized effective bandwidth and bandwidth deviation for fractional-octave band filters are described by IEC 61260-1 (2014) in sections 5.11 and 5.12, respectively. At some normalized frequency $\Omega = f/f_m$ the relative attenuation of a constant amplitude sinusoidal input signal by a given filter is $\Delta A\,(\Omega)$. The normalized response of a filter to such a signal is

$$10^{-0.1\Delta A(\Omega)}$$

The normalized effective bandwidth B_e is determined, in practice, using the following finite integral expression:

$$B_e = \int_{\Omega_{start}}^{\Omega_{end}} \frac{1}{\Omega} 10^{-0.1\Delta A(\Omega)} d\Omega$$

This integral expression should be evaluated using a trapezoidal numerical integration scheme as recommended in section 7.2.3.2 of IEC 61260-2 (2017). For ideal one-third octave band filters with zero relative attenuation in the passband, the normalized reference effective bandwidth is $B_r = 0.230259$. The effective bandwidth deviation ΔB is determined by

$$\Delta B = 10 \log_{10}\left(\frac{B_e}{B_r}\right)$$

8.2.3.2 *Performance Specification*

For each bandpass filter in a set of one-third octave band filters, the acceptance limits for the effective bandwidth deviation are $|\Delta B| \leq \pm 0.4$ dB for class 1 instruments.

8.2.3.3 *Test Guidance*

In section 5.11.2 of IEC 61260-1 (2014) it is noted that filter response may be tested with either a series of constant-amplitude sinusoidal signals or a constant-amplitude exponential frequency sweep. In this section we will present methodology utilizing discrete signals at constant test frequencies as recommended in IEC 61260-2 (2017) for pattern-evaluation testing. The test procedure is essentially the same as that of section 8.3.2 for relative attenuation measurements with the exception of the quantity of and specific frequencies to be tested. For time invariant (real-time) filter sets, as defined in section 5.14 of IEC 61260-1, testing may optionally be conducted using an exponential constant-amplitude sinusoidal sweep. An example test procedure is given in IEC 61260-3 (2017), Annex B.

Although the overall shape of the filter response is captured fairly well with a comparatively small number of points, determination of effective bandwidth deviation by evaluating the integral expression for B_e is adversely affected by low numbers of points. Additionally, frequencies intended to evaluate filter response shape relative to specified minimum and maximum attenuation are clustered in the passband and near the band edges. That distribution of frequencies, however, is not optimal for estimating effective bandwidth deviation. As such, different sets of frequencies should be used to estimate effective filter bandwidth.

To measure effective filter bandwidth, normalized test frequencies should cover a large range such as $0.158 < \Omega < 6.31$. As noted in IEC 61260-1, it is possible to use a set of test frequencies for concurrent testing of a set of one-third octave band filters by capturing the response of all filters to the input signals. For a set of 24 one-third octave band filters with nominal midband frequencies from 50 Hz to 10 kHz, the range of test frequencies should cover Ω_{start} for the lowest midband frequency through Ω_{end} for the highest midband frequency. Applying the range of Ω noted above, this corresponds to a dimensional frequency range of approximately 7.9 Hz to 63,100 Hz. For practical testing, it is recommended to keep the test frequencies within the range of 20 Hz to 20 kHz. The test frequencies should be exponentially spaced such that the spacing is uniform on a base-10 logarithmic scale. A set of test frequencies can be calculated from the following expression:

$$\Omega_i = 50 \times 10^{-0.8+i\times\Delta} \qquad i = 0, 1, \ldots, N-1$$

In this expression, the exponential spacing factor Δ and number of frequencies N should be determined together to ensure the entire frequency range is covered with sufficient resolution. Exact values will depend on the underlying shape of the filters under test, though as a minimum, $\Delta = 0.005$ and $N = 782$ are highly recommended. This equates to roughly 32 test measurements per filter. The test procedure is as follows:

1. On the reference level range, apply a steady sinusoidal signal to the analog input of the DUT.
2. Adjust the input signal level to be $1\ (\pm\, 0.1)$ dB below the upper limit of the linear operating range.
3. Record at least a 30-second sample of the signal. Note the input signal level.
4. For each test frequency, apply the sinusoidal input signal to the filter bank under test while maintaining the signal level set in step 2. Record the input level and output levels for each measurement.
5. Determine the relative attenuation of the filters under test, in decibels, from the one-third octave band levels of the output signals minus the level of the input signal per the methods described in section 8.3.2.3. Resolution to the hundredth of a decibel is recommended for reporting the measurements of output signal levels.
6. Determine the normalized effective bandwidth for each filter by evaluating the integral expression for B_e using a trapezoidal integration scheme as outlined in section 8.3.3.1.
7. Determine the effective bandwidth deviation ΔB for each filter using the appropriate expression in section 8.3.3.1.

NOTE: *When evaluating effective bandwidth using the trapezoidal method and a series of discrete test frequencies, care should be taken to avoid errors introduced by the fence-post effect, a situation where counting of discrete elements needs to account for whether each element represents the midpoint of a smaller trapezoidal area, or one of the boundaries of such an area. If each discrete element represents the midpoint of a smaller trapezoidal area, then the summation can be performed in a straightforward manner by summing the energy within the trapezoidal areas and then dividing by the number of discrete elements. If however, each discrete element represents an upper or lower boundary of a smaller trapezoidal area, there are two additional steps for handling these:*

> *1. For each boundary pair of elements, the value for the smaller trapezoidal area should be determined as the mean of the two boundary values, and;*
>
> *2. The summation of the energy represented by these mean values should be divided by the number of discrete elements minus 1.*

The errors introduced by improper handling of the fencepost effect are typically small in absolute terms but can result in larger errors when smaller numbers of test elements are used.

RECOMMENDATION: Although it may be useful and informative to measure and report effective bandwidth values for 1/3 octave band analysis, the application of corrections for such errors to the 1/3 octave band aircraft noise level data has been historically found to have potential to introduce more error uncertainty than it may correct. Volpe suggests that effective bandwidth error corrections be measured and reported but not applied to aircraft noise certification data.

8.2.3.4 Results

Results of the filter integrated response test should be presented as tabulated values of filter nominal midband frequencies and associated effective bandwidth deviation. The frequency range of the input signals, input signal level, and any other related information should be provided with the table. Numerical values should be presented with sufficient precision to determine if measured values fall within acceptance criteria. An example set of results is provided in table 5. A graphical presentation of the measured filter responses may also be submitted as a supplement to the tabular results. The graph should contain relative attenuation plotted as a function of test frequency, and the figure caption or title should give the input signal level and filter midband frequency or range of frequencies. An example of such a plot is given in figure 4.

Table 5. Effective bandwidth deviation values from simultaneous testing of a one-third octave band filter set. Input signal level is 100 dB

Nominal midband frequency f_m (Hz)	Effective bandwidth deviation ΔB (dB)
50	−0.006
63	−0.001
80	−0.002
100	−0.002
125	−0.002
160	−0.001
200	−0.001
250	−0.002
315	−0.002
400	−0.002
500	−0.002
630	−0.002
800	−0.002
1,000	−0.002
1,250	−0.002
1,600	−0.002
2,000	−0.002
2,500	−0.002
3,150	−0.002
4,000	−0.002

5,000	−0.002
6,300	−0.002
8,000	−0.002
10,000	−0.002

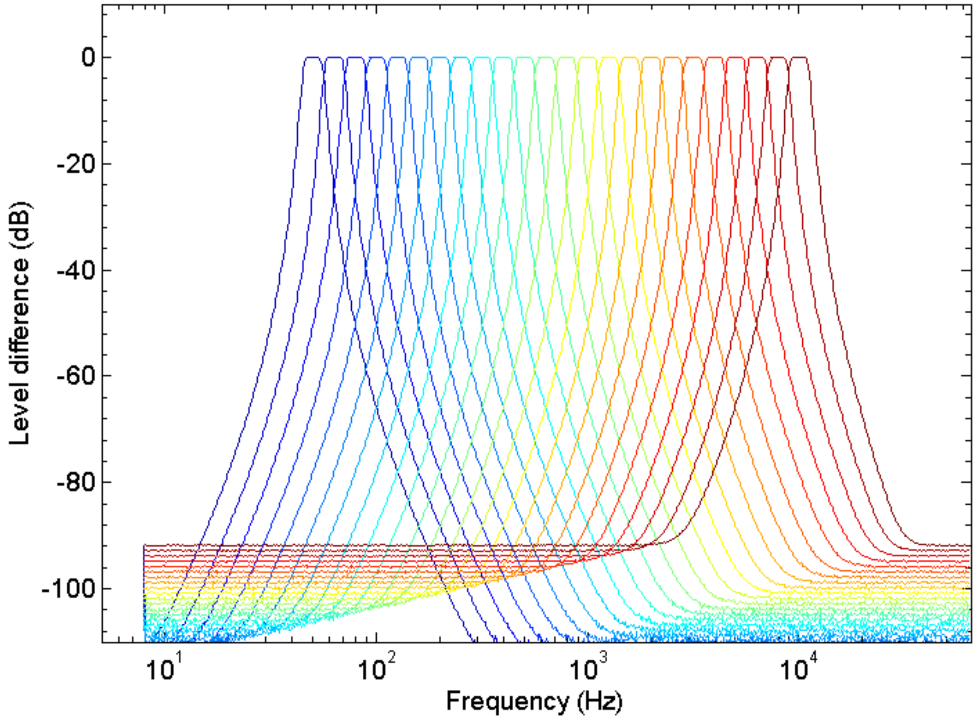

Figure 4. Filter response shapes for a bank of one-third octave band filters with midband frequencies from 50 Hz to 10 kHz, inclusive. Input signal level is 100 dB.

8.2.4 Summation of output signals

8.2.4.1 Objective

This investigation is designed to evaluate attenuation characteristics between the midbands of adjacent filters within a set of one-third octave band filters.

8.2.4.2 Performance Specification

In accordance with IEC 61260-1 (2014), section 5.16, for a sinusoidal input signal at any frequency between two consecutive one-third octave midband frequencies, the acceptance limits for the difference between (a) the level of the input signal minus the reference attenuation and (b) the level of the sum of the time-mean-square output signals from adjacent filters of specified filter bandwidth are +0.8 dB and −1.8 dB for class 1 instruments.

8.2.4.3 *Test Guidance*

1. The test should begin at the one-third octave band filter with the second lowest midband frequency and proceed through each contiguous filter until the filter with the second highest midband frequency is evaluated.
2. Test signal frequencies and the corresponding relative attenuation measurements may be taken from the Relative Attenuation evaluation performed in section 8.3.2.2 of this document. For each filter, test frequencies should span from the upper bandedge frequency of the lower adjacent filter to the lower bandedge frequency of the upper adjacent filter. Steps 3 through 5 describe the methodology of testing and calculation of the summation of output signals.
3. Let j identify a filter in a set of filters with $j-1$ and $j+1$ representing the contiguous filters with midband frequencies lower and higher than for the jth filter. Let ΔA_j, ΔA_{j-1} and ΔA_{j+1} represent measured relative attenuations of the three filters, respectively, at any test frequency.
4. With S equal to the number of test frequencies per filter bandwidth from the relative attenuation tests, let M be equal to the largest integer just less than or equal to $S/2$ and let I be any integer between $-M$ and $+M$ to determine a frequency for a measurement of relative attenuation.
   At any normalized frequency between the lower and upper bandedge normalized frequencies of the jth filter with exact midband frequency f_m, the difference $\Delta P(f_i)$ in decibels between the level of the input signal minus the reference attenuation and the level of the summed output signals is determined from the relationship:

   $$\Delta P(f_i) = 10\log_{10}\left(10^{-0.1\Delta A_{j-1}} + 10^{-0.1\Delta A_j} + 10^{-0.1\Delta A_{j+1}}\right)$$

   Where:

   ΔA_{j-1} is the relative attenuation measured for filter $(j-1)$ measured at normalized frequency $G^{[i/(bS)+1/b]}$;
   ΔA_j is the relative attenuation for filter j measured at normalized frequency $G^{[i/(bS)]}$;
   ΔA_{j+1} is the relative attenuation for filter $(j+1)$ measured at normalized frequency $G^{[i/(bS)-1/b]}$.

5. For each filter bandwidth provided, the difference $\Delta P(f_i)$ is calculated according to the formula in step 5 of this procedure.

8.2.4.4 *Results*

The preferred method of presentation is in tabular form. Table 6 is given as a template, containing all pertinent values to be reported. A separate table should be provided for each filter tested within the one-third octave band filter set.

Table 6. Preferred format for reporting summation of output signals test results

Test signal frequency, f_i (Hz)	Relative attenuation at f_i(dB)			$\Delta P(f_i)$ (dB)	Acceptance limits for class 1 instruments (dB)
	Filter $(j-1)$ ΔA_{j-1} (dB)	Filter (j) ΔA_j (dB)	Filter $(j+1)$ ΔA_{j+1} (dB)		
890.3	3.31	3.66	39.76	−0.47	[−1.8,0.8]
892.3	3.68	3.29	39.52	−0.47	[−1.8,0.8]
919.6	9.79	0.40	36.23	0.07	[−1.8,0.8]
947.2	15.87	0.01	32.70	0.10	[−1.8,0.8]
974.0	20.97	0.00	29.03	0.04	[−1.8,0.8]
1000.0	25.24	0.00	25.20	0.03	[−1.8,0.8]
1026.7	29.07	0.00	20.94	0.04	[−1.8,0.8]
1055.8	32.75	0.01	15.84	0.10	[−1.8,0.8]
1087.5	36.29	0.40	9.77	0.08	[−1.8,0.8]
1121.0	39.61	3.33	3.64	−0.47	[−1.8,0.8]
1123.0	39.80	3.63	3.34	−0.47	[−1.8,0.8]

8.2.5 Real-time (Time-invariant) operation

8.2.5.1 Objective

Verify real-time operation of one-third octave band filters within a set of filters. For the purpose of this document, per IEC 61260-1 (2014), section 5.14.1, real-time operation of the filter set is taken to mean that a time-averaged signal level at the output of the instrument should be the same for all filters when a constant-amplitude sinusoidal signal is applied to the input and the frequency of the signal is varied at an exponential rate over the frequency range of all filters of any given bandwidth.

NOTE: For sampled-data filters operating in real-time, time-invariant operation requires that, on average, the computations associated with each sampling interval are completed in a time period less than or equal *to the sampling interval such that all input data are processed within the sampling interval and all samples of an input signal contribute with equal weight to the resulting filtered output signal level.*

8.2.5.2 Performance Specification

Per part 36/Annex 16, the analysis system should be able to operate in real time from 50 Hz to at least 12 kHz inclusive. For the purposes of this document, this is taken to mean that, at minimum, each one-third octave band filter with a set of filters should demonstrate real-time operation ranging from nominal midband frequencies of 50 Hz to 10 kHz inclusive. This capability applies to all operating channels intended for use in aircraft noise certification testing.

As defined in IEC 61260-1 (2014) The time-averaged signal level, L_{out}, as measured at the output of the one-third octave band analyzer, should be the same for all filters when a constant-amplitude sine signal is applied to the input and exponentially swept over the frequency range of the filter set.

For each filter within a set, when the frequency is swept at a rate of one decade in 2 s to 5 s, the acceptance limits for the deviation of a measured time averaged output signal level, L_{out}, from the corresponding expected time-averaged output signal level, L_c, as determined according to the following expression, is $\pm$0.4 dB for class 1 instruments.

$$L_c = L_{\mathrm{in}} - A_{\mathrm{ref}} + 10\log_{10}\left(\frac{T_{\mathrm{sweep}}}{T_{\mathrm{avg}}}\frac{\log_{10}(f_2/f_1)}{\log_{10}(f_{\mathrm{end}}/f_{\mathrm{start}})}\right)\ \mathrm{dB}$$

Where:

L_{in} is the signal level of the constant amplitude input signal;
A_{ref} is the nominal attenuation in the passband as stated in the filter manual;
T_{sweep} is the elapsed time to perform a logarithmic sweep from the starting frequency (f_{start}) to the ending frequency (f_{end});
f_1, f_2 are the lower and upper bandedge frequencies, respectively;
T_{avg} is the averaging time selected for measurement of the output signal level L_{out}.

8.2.5.3 Test Guidance

1. Connect signal generator[2] to the DUT input.

   NOTE: A method for digitally generating an exponential frequency sweep signal is given in IEC 61260-2:2014, Annex A. The sweep rate, r, is first calculated as:

---

[2] Signal generator should be verified to produce true exponential frequency sweeps per IEC 61260-2, Annex A

$$r = \frac{1}{T_{\text{sweep}}} \ln\left(\frac{f_{\text{end}}}{f_{\text{start}}}\right)$$

For sampling rate f_s, discrete samples in the digital signal at each point $n = 1, \ldots, T_{sweep} \times f_s$ can be calculated as follows:

$$s_n = \sqrt{2} \sin\left(\frac{2\pi}{r} f_{\text{start}} \left[e^{\frac{rn}{f_s}} - 1\right]\right)$$

2. From the established reference level and at the reference frequency of 1 kHz, adjust amplitude at the signal generator so that the test signal is 3 dB below the upper limit on the reference level range.
3. Set signal generator to sweep from 0.01 Hz to 1 MHz at the signal level established in step 2. This represents a sweep range of eight decades.
4. Set sweep rate between 2 to 5 seconds per decade. For example, if the sweep period is set to 30 seconds, this corresponds to 3.75 seconds per decade.
5. The same time interval used for the sweep period should be used for the averaging time of the analyzer.
6. Begin integration period at analyzer, then within 0.5 to 1.5 seconds begin the frequency sweep. This sequence will ensure that the averaging at the analyzer is completed before the sweep is finished by the same amount of time, thus mitigating potential deviations resulting from the signal generators return to the starting frequency upon completion of the sweep. Additionally, the sweep frequency when the averaging is finished will be well above the upper bandedge frequency for the filter with the highest midband frequency and also above the frequency where the attenuation is at least 55 dB.
7. The difference between the measured output level and the expected output level, L_c, represents the deviation from time invariant operation and should be within the acceptance limits stated in section 8.3.5.2.
8. Depending on the synchronization between the filters, some non-real-time filters may respond correctly on the sweep test. It may, therefore, be necessary to repeat the above tests up to a maximum of three times to establish real-time operation.

8.2.5.4 Results

It is recommended to present results in a tabular format displaying, at a minimum, the filters of interest from 50 Hz to 10 kHz. Along with table, include input signal level, reference attenuation, sweep frequency range, sweep time, and averaging time. Table 7 is given as an example set of test results. In the example given,

$L_{\text{in}} = 114 \text{ dB}$;
$A_{\text{ref}} = 0 \text{ dB}$;
$T_{\text{sweep}} = T_{\text{avg}} = 30 \text{ sec}$;
$f_{\text{start}} = 0.01 \text{ Hz}$; and

$f_{\text{end}} = 1$ MHz.

Table 7. Preferred presentation of results for verification of real-time operation

Nominal midband frequency, f_{nom} (Hz)	Measured output level, L_{out} (dB)	Expected output level, L_c (dB)	Deviation, $L_c - L_{\text{out}}$ (dB)	Acceptance limit for class 1 instruments (dB)
800	94.963	94.969	0.006	±0.4
1000	94.962	94.969	0.007	±0.4
1250	94.962	94.969	0.006	±0.4
1600	94.963	94.970	0.007	±0.4

8.2.6 Anti-alias filtering

8.2.6.1 *Objective*

Ensure the presence and effectiveness of low-pass, anti-alias, filtering prior the analog-to-digital conversion process.

8.2.6.2 *Performance Specification*

IEC 61260-1 (2014), section 5.15, states that the manufacturer should include analog and digital anti-alias filters, as appropriate, in a sampled-data or digital filter system. Anti-alias filters should minimize interference between an input signal and the sampling process that would cause the relative attenuation response to exceed the minimum or the maximum acceptance limits on relative attenuation presented in section 8.3.2.2, Table 2.

Additional performance specifications for anti-aliasing effectiveness are given in Part 36, Appendix A, Section A36.3.3.2 (Also, Annex 16, Appendix 2, Section 3.3.2), “for any component of the measurement system which converts an analog signal to digital form”. Detailed guidance is provided in section 8.3.3 of this document.

8.2.6.3 *Test Guidance*

For analysis components of the noise certification instrumentation system that include digitization of analog signals to digital form, measurement of anti-aliasing is limited by the settings and characteristics of the DUT itself. For evaluating aliasing components in the analysis system, 1/3 octave band levels should be sufficient to identify the presence and/or strength of aliased components resulting from the presence of out of band signals at the input. For specific details on anti-alias testing of the recording /reproducing system components, and for guidance on selection of input signals for anti-alias testing for analysis components, see Section 8.3.3 of this document. The following conditions should be met for any digitally-based one-third octave band analyzer:

1. Documentation provided by the manufacturer should state the presence of analog and, optionally, digital low-pass filtering for anti-aliasing.
2. The DUT should meet or exceed the acceptance limits of the performance specification for relative attenuation as performed in section 8.3.2.
3. Anti-aliasing effectiveness testing and compliance to the acceptance limits as presented in section 8.3.3 of this document is recommended.

8.2.7 Data interval and data loss

8.2.7.1 Objective

Ensure that all acoustic data has been acquired and stored in the specified time interval without any unintended loss of data.

8.2.7.2 Performance Specification

Per Part 36, Appendix A, Section A36.3.7.2(c) (and Annex 16, Appendix 2, Section 3.7.2(c)), the interval between successive sound pressure level samples should be $500 \text{ ms} \pm 5 \text{ ms}$ for spectral analysis with or without slow time-averaging. For those analysis systems that do not process the sound pressure signals during the period of time needed for readout and/or resetting of the analyzer, the loss of data should not exceed a duration of 5 ms.

8.2.7.3 Test Guidance

Since virtually all analysis systems currently used in aircraft noise certification testing rely on sampled-data and digitization, it is recommended that this test be performed as a time series or sample counting exercise, using a test signal containing continuous timing information, such as IRIG-B. Prior to testing, please refer to the device user documentation to ensure that the sampling rate (Hz), per channel, as configured for noise certification testing, is fully understood.

1. Set up the time code generator/time server to output a continuous timing signal, and using multiple output channels or signal splitters, if required, simultaneously connect to each input of the DUT intended for use during aircraft noise certification testing. If the number of channels used is variable, then use the maximum number that may be used during testing.
2. Adjust signal level to within 10 dB of the upper limit on the reference level range. Signal attenuators may be required.
3. Apply a shorting cap or dummy load to the DUT inputs/channels not being used.
4. Enable data collection at the analyzer at the 0.5 second interval, as typically configured for aircraft noise certification testing, for at least 10 minutes.

8.2.7.4 Results

Data files produced by analyzers are stored in many formats, often proprietary. Manufacturers provide software and documentation in order to view, interpret and apply these files for various end-uses, such as using third party analysis and programming tools, e.g., MATLAB. In most cases, manufacturer provided software will have turn-key functionally to view both total samples per measurement, as well as samples per data interval. This information should be used to verify the completeness of data.

1. If samples per 500 ms data interval are available, a direct comparison of samples per contiguous data intervals may be made over the duration of the measurement period. A ± 1 % acceptance criterion may be used to verify that the expected number of samples per each 0.5 sec interval matches the actual number of samples per data interval over the duration of the test data file.

   For example;
   a. assume a DUT has a data rate of 51200 samples per second (Hz). $51200/2 = 25600$ which is the expected sample count for a 500 ms period.
   b. hence, the 1 % acceptance criterion for data loss per data interval would be determined by 25600 - 256 samples.
   c. expected samples per 0.5 sec interval should be 25600, however sample counts down to 25344 per 0.5 sec interval would be considered acceptable.

2. Alternatively, if the DUT software does not indicate samples per data interval, the total number of samples in the test measurement period must be used to determine data completeness. Although this information will not yield the needed resolution to determine if every 0.5 sec record is complete, it may be viewed as a litmus test to determine if there are any significant issues regarding unintended data loss.

   For example;
   a. If a DUT has a data rate of 51200 samples per second (51200 Hz) and a 10 minute test file is recorded, then the total number of expected samples will be 600 (sec) x 51200 (Hz) = 30,720,000 samples.
   b. hence, the 1 % acceptance criterion for the measurement period would be 307,200 samples, or 6 seconds of data if measured in time.
   c. expected sample total for the 10-minute measurement would be 30,720,000, however a sample total of 30,412,800 would be the minimum acceptance criterion.

   NOTE: exactly 10 minutes was used to create a simple example. It is not necessary to precisely time the length of the test data file. The key is to compare the actual sample count with number of samples expected from the start timestamp to the end timestamp.

3. Preferred data presentation is in tabular form. Due to the large amount of data points, it is

recommended to include the results as a separate spreadsheet attachment, e.g., Excel file, when submitting the test report. Please include a results data tab for each channel tested.

4. Data should include DUT sample rate as configured, starting and ending timestamps of test measurement file, acceptance limit for 0.5 second data intervals, expected samples per data interval and actual sample count per data interval. Please highlight any results that fall outside the acceptance limit.
5. If data interval resolution is not available, please provide acceptance limit, expected samples and actual samples for the entire measurement test file.

8.2.8 Slow – time averaging response (if applied in the analyzer)

8.2.8.1 Objective

To ensure the analyzer is properly applying a slow exponential averaging process (SLOW weighting) with a nominal 1-second time constant, as defined in Part 36/Annex 16.

8.2.8.2 Performance Specification

In accordance with Part 36, Appendix A, Section A36.7.4 And updated in Annex 16, Appendix 2, Section 3.7.4), the response of the one-third octave band analysis system to a sudden onset or interruption of a constant sinusoidal signal at the respective one-third octave nominal midband frequency should be measured at sampling instants 0.5, 1, 1.5 and 2 seconds after both the onset and interruption of the test signal. The rising response should be –4 ± 1 dB at 0.5 seconds, –1.75 ± 0.75 dB at 1 second, –1 ± 0.5 dB at 1.5 seconds and –0.5 ± 0.5 dB at 2 seconds relative to the steady-state level.
The sum of the rising and corresponding falling shall be –6.5 ± 1 dB, at both 0.5 and
1 seconds. The sum of the rising and falling responses (Updated in Annex 16) shall be –6.5 dB or less at 1.5 seconds and –7.5 dB or less at 2 seconds, and subsequent times relative to the steady-state levels.

8.2.8.3 Test Guidance

1. Apply a steady sinusoidal electrical signal at the nominal midband frequency of 50 Hz to the input of the DUT.
2. Adjust signal level to indicate a level that is 3 dB less than the upper boundary of the linear operating range on the reference level range. Shut off the test signal
3. Begin data collection using 500 ms interval with slow time averaging enabled.
4. After at least 10 seconds of data collection, abruptly start the test signal.
5. After at least 10 seconds of data collection, abruptly shut off test signal and continue to collect data for a minimum of 10 additional seconds.
6. Repeat steps 1 through 5 for each nominal one-third octave midband frequency to 10 kHz inclusive.
7. Using the recorded time history data, for each nominal one-third octave midband frequency,

calculate level changes relative to initial steady-state level, at specified instants from onset and calculate output signal summations, at specified instants, after interruption of test signal.

8.2.8.4 *Results*

1. Results should be presented in tabular form.
2. Preferred format includes a row for each test frequency and a column for the initial steady state signal level, the measured levels at specified instants after onset, the rising response (level differences after onset) and the summation of output signals characterizing falling response. An example is provided below and may be used as a template for filling in test results.

Table 8. Preferred format for presentation of slow time-averaging response results

Test Freq. (Hz)	Steady State Signal Level (dB)	Rising Response (dB)				Sum of the rising and corresponding falling responses (dB)			
		0.5 s: (−4 ±1 dB)	1.0 s: (−1.75 ±0.75 dB)	1.5 s: (−1 ±0.5 dB)	2.0 s: (−0.5 ±0.5 dB)	0.5 s / 1.0 s: (−6.5 ±1 dB)		1.5 s: (≤−6.5 dB)	2.0 s: (≤−7.5 dB)
50	114.00	−4.67	−2.22	−1.21	−0.69	−6.56	−6.28	−7.44	−9.09
63	114.00	−4.53	−2.17	−1.18	−0.68	−6.48	−6.29	−7.47	−9.14
80	114.00	−4.42	−2.13	−1.16	−0.67	−6.41	−6.30	−7.50	−9.18
100	114.00	−4.34	−2.10	−1.15	−0.66	−6.37	−6.30	−7.52	−9.20
125	114.00	−4.29	−2.08	−1.14	−0.66	−6.35	−6.31	−7.54	−9.23
160	114.00	−4.23	−2.06	−1.13	−0.65	−6.31	−6.31	−7.56	−9.25
200	114.00	−4.19	−2.04	−1.12	−0.65	−6.29	−6.31	−7.56	−9.27

8.2.9 Overload indication

8.2.9.1 *Objective*

To ensure that an overload condition, associated with any band in a bank of filters, is both displayed in real time to inform the operator and also indicated in stored data, so that there will be a permanent record of the overload condition.

8.2.9.2 *Performance Specification*

Per IEC 61260-1 (2014), section 5.17, the instruction manual should describe the operation and interpretation of overload indication(s).

An overload indication should be displayed before the acceptance limits for level linearity deviation and relative attenuation are exceeded. This requirement applies to all level ranges and for any frequency in the range from the lower bandedge frequency for the filter with the lowest midband frequency to the upper bandedge frequency of the filter with the highest midband frequency in a set of filters.

The overload indication should be presented as long as the overload condition exists, for at least 1 s, and should remain displayed as long as the measurement result is displayed.

Additionally, a record of the overload indication and the affected time period should be clearly represented in the stored data.

8.2.9.3 Test Guidance

1. First, consult the DUT Instruction Manual to verify the presence on an overload indicator and understand the intended functionality.
2. On the reference level range, apply a sinusoidal signal to the input of the DUT at the lower bandedge frequency of the filter with the lowest midband frequency in the set, e.g., if 50 Hz is the lowest nominal midband frequency in the set, then 44.7 Hz would be the test frequency.
3. Adjust the level so that the overload indicator is triggered, then back off the level till it goes off.
4. Enable data recording. After 10 seconds, increase amplitude of test signal by 0.1 dB increments until overload indicator is triggered and remains on.
5. Note level at which indicator was triggered and continue to record data.
6. Decrease level of test signal below threshold where indicator was triggered and stop data collection after 10 seconds.
7. Note if the presence of the indication overload remained on the display after the level was reduced and data recording at the analyzer was disabled.
8. Repeat steps 2 through 7 using a sinusoidal test signal at the upper bandedge of the filter with the highest midband frequency in the set, e.g., if the highest filter in the set has a nominal midband frequency of 10 kHz, then apply a 11.2 kHz test frequency.
9. For any other level range that may be used for aircraft noise certification testing, repeat steps 2 through 8.

8.2.9.4 Results

1. Provide excerpt from DUT Instruction Manual explaining operation of overload indication.
2. Provide table for each level range tested and include fields for sinusoidal test frequency, starting level, level at which overload indicator initiates and whether the indicator remained apparent after the level was decreased below the indicator threshold.
3. Include screenshot of stored data where overload occurred in data submittal. one-third octave band data file viewable in common format, such as Microsoft Excel is also permissible.

8.3 Data Recording and Reproducing System Performance Tests

8.3.1 Level linearity

8.3.1.1 Objective

At any test frequency, ideal level linearity means there is no difference between a measured input signal level and the corresponding expected output signal level, based on a known adjustment of the input level to the DUT. Level-linearity errors are deviations from ideal level-linearity.

Evaluate level-linearity errors to determine the upper and lower boundaries and the extent of the linear operating range of the DUT at various frequencies over the range of interest for aircraft noise certification testing.

NOTE: In some digital audio recorders, it is possible for an overload condition, as defined in Section 5.25, to occur prior to the maximum allowable level-linearity error, as defined in Part 36/Annex 16. In such cases, the upper boundary of the level range should be defined by the onset of an overload condition, not the exceedance of the applicable acceptance limit for level linearity errors.

8.3.1.2 Performance Specification

In accordance with Part 36, Appendix A, Section A36,3.6.5, Note 1 (and the Recommendation provided under Annex 16, Appendix 2, Section 3.6.5), level linearity of measurement systems should be tested according to the methods described in IEC 61265 as amended. IEC 61265 - Edition 2.0, 2018 states level-linearity errors of the entire measurement system, exclusive of the microphone, but including the microphone preamplifier, and any other signal-conditioning elements that are considered to be part of the microphone system, at one-third-octave mid-band frequencies between 50 Hz and 10 kHz, shall not exceed ± 0.4 dB on the reference level range, and ± 0.5 dB on other relevant level ranges, for a linear operating range of at least 50 dB.

On the reference level range, the level corresponding to the calibration sound pressure level shall be at least 5 dB, but no more than 30 dB less than the upper boundary of the level range.

8.3.1.3 Test Guidance

1. On the reference level range, or any level range intended for use in aircraft noise certification testing, level linearity should be tested with sinusoidal electrical signals with one-third octave nominal midband frequencies between 50 Hz and 10 kHz, and the calibration check frequency, if it is not one of the recommended frequencies, e.g., 250 Hz.
2. At any test frequency and for any level range, the expected level of a DUT output signal indicated by the one-third octave band spectrum analyzer should be calculated from the level of the starting point on the reference level range plus the change in the level of the input signal relative to the level of the input signal used to establish the starting point.

NOTE: Changes in the level of the input signal may be determined from changes to the setting of the signal generator or input signal attenuator. Accuracy of intended level changes may be confirmed via *direct measurement of the test signal by the one-third octave band spectrum analyzer.*

3. At a selected test frequency, tests of level linearity begin at the starting point on the reference level range. Record the input signal, as determined in section 8.2, to the DUT and play back through the spectrum analyzer. Note the 10-second averaged output signal level as indicated by the spectrum analyzer. Level linearity error is zero at the starting point on the reference level range.
4. The procedure in step 3 is then repeated with the level of the input signal increased sequentially above the starting point in steps no greater than 5 dB (preferably 1 dB) up to and beyond the indication of overload, and then down from the starting point to the first indication of underrange (if provided) and into the region where self-generated noise causes substantial level-linearity errors. If applicable, for level ranges other than the reference level range, 10 dB steps in the input signal level may be used up to within 5 dB of the upper boundary and down to within 5 dB of the lower boundary.

   NOTE 1: Increments or decrements in the level of the input signal may need to be less than 1 dB in the regions near the upper and the lower boundary of the linear operating range to provide adequate resolution.

   NOTE 2: Level-linearity tests at input signal levels up to 5 dB greater than the upper boundary, or down to 5 dB less than the lower boundary, of the linear operating range should be sufficient.

5. Tabulate the expected output signal level for a given input signal level, the corresponding measured output signal level as indicated at the one-third octave band spectrum analyzer, and the level-linearity error.
6. Steps 3, 4, and 5 should be repeated for each additional one-third octave nominal midband frequency between 50 Hz and 10 kHz.

8.3.1.4 Results

Table 9 shows the preferred format for reporting results of a level-linearity test for a 10 kHz test frequency on the reference level range of an example DUT. Signal levels should be reported to 0.01 dB, if available, otherwise to 0.1 dB. The example in Table 9 indicates that the upper boundary of the linear operating range is 121 dB; the lower limit is 19 dB, and the extent of the linear operating range is 102 dB.

Table 9. Recommended format for level-linearity test results: 10 kHz test frequency on the reference level range

Expected DUT output signal level (dB)	Measured DUT output signal level (dB)	Level linearity error (dB)
126.00	123.19	−2.81
125.00	122.69	−2.31

124.00	122.47	−1.53
123.00	122.12	−0.88
122.00	121.46	−0.54
121.00	120.77	−0.23
120.00	119.89	−0.11
119.00	118.95	−0.05
118.00	117.98	−0.02
117.00	116.99	−0.01
116.00	115.99	−0.01
115.00	115.00	0.00
114.00 (ref)	114.00	0.00
109.00	108.99	−0.01
104.00	103.99	−0.01
99.00	98.99	−0.01
94.00	94.01	0.01
89.00	89.01	0.01
84.00	83.99	−0.01
79.00	79.00	0.00
74.00	73.99	−0.01
69.00	69.01	0.01
64.00	64.02	0.02
59.00	59.02	0.02
54.00	54.02	0.02
49.00	49.03	0.03
44.00	44.03	0.03
39.00	39.08	0.08
34.00	34.11	0.11
29.00	29.23	0.23
24.00	24.32	0.32
19.00	19.37	0.37
18.00	18.51	0.51
17.00	17.67	0.67
16.00	16.73	0.73
15.00	16.66	1.66
14.00	15.85	1.85

8.3.2 Overload indication and characteristics

8.3.2.1 Objective

Ensure the presence and functionality of an overload indicator that alerts users both in real-time and playback that an overload condition has occurred. Evaluate the influence of harmonic distortion and self-generated noise of a DUT as the level of a sinusoidal input signal approaches and exceeds the upper boundary of the linear operating range on the reference level range. In addition, characterize the transition of the input signal between the upper boundary of the linear operating range and an overload condition, as well as the relationship between the operation of the overload indicator on the DUT and the distortion of a recorded signal.

8.3.2.2 Performance Specification

Part 36, Appendix A, Section A36.3.6.8 (and Annex 16, Appendix 2, Section 3.6.8) includes a specification for the measurement system for aircraft noise certification testing to provide an indication of the overload that occurs during an overload condition on any relevant level range. Additionally, it is recommended that the overload characteristics of the system be explored through both the measurement of total harmonic distortion + noise (THD+N) and a visual inspection of the sinusoidal test signal as it approaches and exceeds the DUT overload indication.

8.3.2.3 Test Guidance: THD +N measurement

The following steps are recommended for evaluating the influence of harmonic distortion and self-generated noise (THD + N) on measurements of sinusoidal output signals.

1. Apply a 1 kHz sinusoidal test signal, at an input signal level corresponding to 5 dB less than the upper boundary of the linear operating range on the reference level range, to the analog input of the DUT. If testing an entire measurement system, insert signal at the microphone preamplifier.
2. Record a 30-second sample of the signal.
3. Play back the recorded 1 kHz test signal and apply a non-attenuating 20 Hz-to-20 kHz bandpass filter.

   NOTE: A nominal 20 Hz-to-20 kHz bandpass filter is recommended to limit the influence of out-of-band self-generated noise on measurements of output signal levels. The specified bandedge frequencies may be varied, however they should not exhibit attenuation characteristics in the 20 Hz-to-20 kHz bandwidth commonly associated with commercial audio devices.

4. Measure the level of the bandpass filtered output signal.
5. Play back the recorded test signal again, but this time apply a narrow band-reject or “notch” filter to remove the 1 kHz fundamental spectral component. The Q factor (refer to section 5.26) of the band-reject or notch filter should be between 1 and 5. Apply the 20 Hz-to-20 kHz bandpass filter to the remaining signal. Harmonics, self-generated noise, and other artifacts should be all that remain.
6. Measure the level of the notch-filtered and bandpass-filtered output signal.
7. Calculate the contribution of THD + N as a percentage of the root-mean-square total signal by the following expression:

$$\mathrm{THD} + \mathrm{N} = (100)\ [10^{(L_2 - L_1)/20}]$$

In the above expression, L_2 is the level (dB) of the notch-filtered and bandpass-filtered output signal from step 6 and L_1 is the level (dB) of the total signal at the output of the bandpass filter from step 4. Signal levels are expressed in decibels.

NOTE: As examples:

if $L_2 - L_1 = -40$ *dB, THD + N = 1.00 %.*

If $L_2 - L_1 = -60$ *dB, THD + N = 0.10 %.*

8. Repeat steps 1 through 7 with input signal levels increased in 1 dB increments. Testing may be terminated when the influence of THD + N reaches, or exceeds, 1 % or the level difference is less than −40 dB.

8.3.2.4 Test Guidance: Visual analysis of overload condition

1. Apply a nominal 20 Hz-to-20 kHz bandpass filter to the output of the DUT.
2. If evaluating a stand-alone recording device, connect the bandpass filtered output to a spectrum analyzer and, optionally, to an oscilloscope. An FFT spectrum analyzer is recommended. If an FFT spectrum analyzer is not available, a set of one-third octave band, or narrower fractional-octave band filters, may be used. Fractional-octave band filters should conform to the class-1 specifications of IEC 61260-1 (2014).

   NOTE: For integrated recording/analysis systems, evaluation of the recorded signal may be performed within the system software.

3. Play back the test signal that was recorded in step 2 of the procedure for measurement of THD+N.
4. Store the resulting spectrum analysis, or time-domain (oscilloscope) analysis, or both, and label the displays with relevant information including the result of the corresponding THD+N test and include in the test report.
5. Repeat steps 1 through 4 with input signal levels increased in 1 dB increments using the signals that were recorded for the THD+N test.
6. Continue the process until an overload condition is clearly observed. Testing may be terminated at the input signal level that causes THD + N = 1 %.

   NOTE: Special attention should be paid to the operation of the Overload Indication on the DUT. It is important to characterize the behavior of the overload indication by noting the input signal level at which it activates, and whether the indication corresponds to an actual overload condition or is merely a warning that further increases in input signal level will cause an overload.

8.3.2.5 Results

The THD + N results should include reference information such as the frequency and level of the input signal, the settings of the controls, the level range, and the bandwidth of the filter on the output of the DUT as well as the Q factor of the notch filter.

NOTE: An example of the reporting of THD + N results is as follows:

> *THD + N = 0.03 % [corresponding to a level difference,* $L_2 - L_1 = -70.5$ *dB] for a 1 kHz input signal recorded at 3 dB less than the upper boundary of the linear operating range on the reference level range and with a 20 Hz-to-20 kHz bandpass filter on the output of the DUT.*

Visual records of overload conditions should include plots of the narrow-band harmonic components in the spectrum accompanied by the corresponding THD + N results noted above. If available, the visual records of the waveform from the oscilloscope images should be provided to supplement the spectral plots.

Image capture options will vary with the signal analyzer used. An analyzer-generated image is preferred; however other suitable methods include, but are not limited to: detailed photographs of the analyzer display screen, printing a screen capture, or converting numerical data to plot graphs in a spreadsheet. Figure 5 shows an example of a DUT overload condition with superimposed plots of the spectral data from an FFT analysis and the corresponding waveform from an oscilloscope trace. The plot in Figure 3 was generated from a single analyzer capable of simultaneously displaying the results of both the frequency and time-domain analyses.

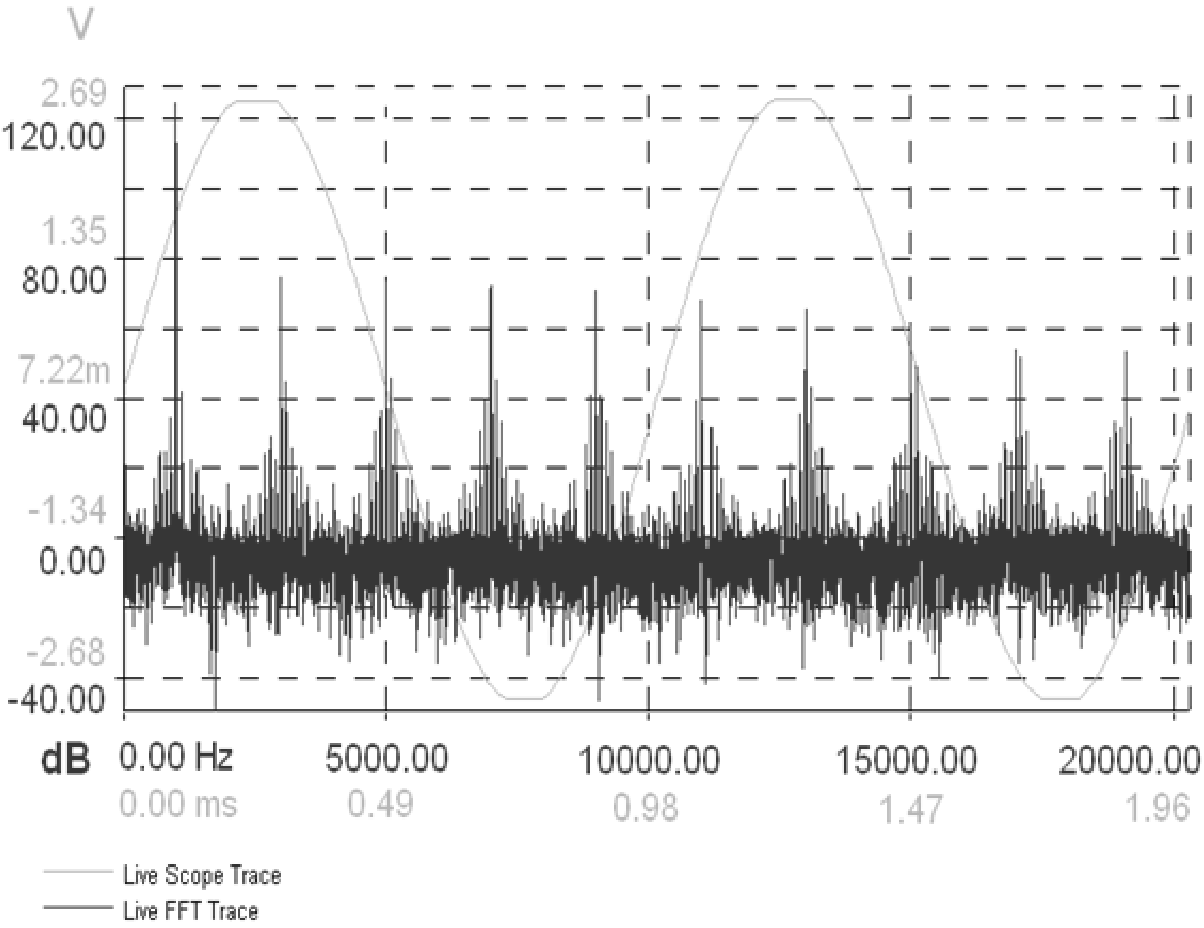

Figure 5. Visual displays of a DUT overload condition for a 1 kHz input signal recorded at 1 dB above the upper boundary of the linear operating range on the reference level range. A 20 Hz-to-20 kHz bandpass filter was applied to the output of the DUT. The corresponding THD + N = 1.2 % with a level difference of −38.5 dB.

8.3.3 Anti-aliasing effectiveness

8.3.3.1 Objective

Determine the effectiveness of the low-pass anti-alias filtering for suppression of alias components inherent to an analog-to-digital conversion process.

NOTE: Digital audio components and systems can exhibit a wide range of anti-aliasing effectiveness. Older, lower-cost instrumentation is typically more likely to exhibit aliasing, while more recently designed instrumentation typically has resolved the situation through use of techniques such as many-times oversampling, decimation, or other methods to eliminate or minimize the potential for aliasing. In every case there should be at least some analog low-pass filtering component prior to the input of the analog-to-digital-converter.

8.3.3.2 *Performance Specification*

In accordance with Part 36, Appendix A, Section A36.3.3.2 (and Annex 16, Appendix 2, Section 3.3.2), the level of any aliased spectral components or spectral artifacts must be at least 50 dB below the upper boundary of the linear operating range, for any frequency below 12.5 kHz. Low-pass anti-alias filtering must be provided prior to sampling by the analog-to-digital converter in the DUT. Note that such analog low-pass filtering may be intrinsic to the analog-to-digital converter, as in the case of delta-sigma converters.

8.3.3.3 *Test Guidance*

For the recording/reproducing components of the system, it is recommended to include external measurement of the signal using bench equipment capable of extended frequency response, in order to quantify the effects of input signals having frequency components substantially greater than the Nyquist Frequency (i.e., the “folding” frequency, or 0.5 times the sampling frequency). Alias testing should be performed on the signal which has been recorded and subsequently reproduced using the settings that would be applied during noise certification testing. (See Section 8.2.6 of this document for guidance on alias testing for analysis system components.)

1. On the reference level range, apply a sinusoidal signal, at a frequency that is at least 2 kHz below the Nyquist frequency (i.e., one-half of the sampling frequency), to the analog input of the DUT. The level of the input signal should be equal to the upper boundary of the linear operating range at 1 kHz.
2. Connect the analog output of the DUT to the input of a spectrum analyzer, if required. FFT spectrum analysis is preferred for detailed frequency domain evaluation. However, a one-third octave band spectrum analyzer should provide sufficient data to indicate that the aliased frequency components have been adequately suppressed.
3. Record a 10 second duration of the signal described in item 1 of this list.
4. Play back the test signal and view the spectrum with the best available resolution while maintaining a view of the bandwidth of interest to at least 30 kHz. For this purpose, it may be helpful to use a linear frequency scale on the x-axis instead of logarithmic.
5. Identify and note the frequency and signal level of the input signal and the corresponding alias component. Use caution to avoid confusing the alias artifacts with, normally present, harmonics of the test signal frequency.

   NOTE: The frequency of an aliased component for an input signal frequency higher than the Nyquist frequency can be calculated from the absolute value of the difference between the closest integer multiple of the sampling frequency and the input frequency:

   $$\mathbf{F_a(k) = |\,(\pm k * F_s) - F_i\,|}$$

   Where:

$F_a(k)$ is the frequency of the alias occurring from integer multiple k times the sampling frequency;
F_s is the sampling frequency;
F_i is the input frequency causing an alias;

For example, with a 48 kHz sampling frequency, and a corresponding 24 kHz Nyquist frequency, the frequency of the aliased component for a 25 kHz input signal frequency would be 23 kHz:

23 kHz = |(-1 * 48 kHz) - 25 kHz|;

If the test signal frequency is raised to 28 kHz, the frequency of the aliased component would be 20 kHz:

20 kHz = |(-1 * 48 kHz) – 28 kHz|;

For an input signal frequency of 51 kHz, the frequency of the aliased component would be 3 kHz:

3 kHz = | (-1 * 48 kHz) – 51 kHz|;

For an input frequency of 66 kHz, the frequency of the aliased component would be 18 kHz:

18 kHz = | (-1 * 48 kHz) – 66 kHz|;

Or, for out of band aliasing:

30 kHz = | (2 * 48 kHz) – 66 kHz|;

6. Repeat steps (3) through (5) in this list for the other test frequencies. The sequence of test frequencies will vary depending on the sampling frequency used by the DUT. The range of test frequencies should begin at least one kilohertz below the Nyquist frequency [from step (1)] and increment to at least twice the Nyquist frequency, that is, at least up to the sampling frequency. The recommended progression of test frequencies is as follows:

   a. Begin using increments of 500 Hz above the initial test frequency.
   b. Further reduce the increments to 200 Hz when within ±1 kHz of the Nyquist frequency.
   c. Once the test signal frequency is greater than 2 kHz above the Nyquist frequency, continue increasing the frequency of the input signal in 2 kHz increments.
   d. Use additional test frequencies to measure the aliased components at 12.5 kHz, 1 kHz, and 500 Hz.
   e. The recommended final test frequency is twice the Nyquist frequency, which will produce an alias artifact at 0 Hz. The level of low-frequency aliases will typically be suppressed below the level of the self-generated noise of the DUT and hence will not be measurable well before this point.
   f. Testing at input signal frequencies greater than the sampling frequency is not required.

However, it is recommended to explore this region with input signal frequencies greater than the sampling frequency to ensure that no unanticipated anomalies are produced within the bandwidth of interest.

7. For reference, the analysis output data should be stored directly, if possible, or the analyzer display can be stored and printed, photographed or plotted, for each test frequency, with appropriate labeling. The labeling should include the bit depth, sampling frequency, and Nyquist frequency.

8.3.3.4 Results

Table 10 shows the preferred format for presentation of data demonstrating that the anti-alias filter produces adequate suppression of aliased spectral components in the frequency range of interest up to 12.5 kHz.

Column 1 of Table 2 lists the frequencies, in hertz, of the input sinusoidal signals. The frequencies were chosen according to the procedure described above. For this example, the DUT uses a sampling frequency of 48 kHz; hence the Nyquist frequency is 24 kHz. The example sequence begins 2 kHz below the Nyquist frequency, i.e., at 22 kHz.

Column 2 lists the levels of the DUT output at each test frequency, in decibels, as indicated by FFT analysis. Columns 3 and 4 of Table 2 list the frequencies and levels of the aliased components of the input signal. The levels of the aliased components in column 4 were determined from the FFT analysis.

Column 5 lists alias suppression (dB) which is calculated by subtracting each alias level from the upper boundary of the linear operating range, on the reference level range. These values will determine compliance to the performance specification cited in section 8.3.3.2.

Table 10. Recommended format for results from anti-alias filter testing. Suppression of alias frequency components is > 89 dB from 12.5 kHz to 0 Hz relative to the upper boundary of the linear operating range (121 dB). The sampling frequency is 48 kHz. The Nyquist frequency is 24 kHz

Input signal frequency (Hz)	**Indicated DUT output at test frequency** (dB)	**Alias frequency** (Hz)	**Alias level** (dB)	**Alias Suppression** (dB)
22000	120.6	26000	54.6	66.4
22500	120.4	25500	92.3	28.7
23000	120.3	25000	94.1	26.9
23200	119.5	24800	98.8	22.2
23400	118.6	24600	103.7	17.3
23600	117.2	24400	109.5	11.5
23800	115.7	24200	111.2	9.8
24000	116.4	24000	116.4	4.6

24200	106.5	23800	110.3	10.7
24400	99.3	23600	107.6	13.4
24600	89.0	23400	103.2	17.8
24800	77.8	23200	98.5	22.5
25000	69.1	23000	92.8	28.2
25500	30.7	22500	77.6	43.4
26000	28.5	22000	59.9	61.1
28000	27.6	20000	34.3	86.7
30000	28.8	18000	32.6	88.4
32000	27.3	16000	32.1	88.9
34000	29.8	14000	30.8	90.2
35500	28.2	12500	31.4	89.6
36000	29.1	12000	30.3	90.7
38000	27.4	10000	31.8	89.2
40000	28.7	8000	29.6	91.4
42000	28.9	6000	30.7	90.3
44000	27.3	4000	31.2	89.8
46000	28.6	2000	30.0	91.0
47000	27.9	1000	30.4	90.6
47500	26.3	500	29.8	91.2
48000	27.1	0	30.1	90.9

NOTE: for the example provided in Table 10 the DUT meets the performance requirements, as the alias levels measured for aliases below 12.5 kHz (darker shading) are all at least 50 dB below the level of the input signal at the upper boundary of the level operating range.

8.3.4 Frequency response

8.3.4.1 Objective

Characterize the ability of a DUT to record, store, and reproduce sinusoidal electrical signals over a range of frequency and within specified acceptance criteria.

8.3.4.2 Performance Specification

To satisfy the requirements of Part 36, Appendix A, Section A36.3.6.3 (and Annex 16, Appendix 2, Section 3.6.3), the relative frequency response should not exceed ±1.5 dB over the range of nominal one-third octave midband frequencies from 50 Hz to 10 kHz. For recordings of constant-amplitude sinusoidal input signals, relative frequency response is determined from the deviation of a one-third octave band output signal level from the one-third octave band output signal level at the calibration check frequency.

In addition, at any frequency over the range from 10 kHz to 11.2 kHz, the deviation of the output signal level from the output signal level at 10 kHz should not exceed ±0.3 dB.

8.3.4.3 Test Guidance

1. Apply a sinusoidal electrical signal at the calibration check frequency to the analog input of the DUT.
2. Adjust the input signal level to be within 5 dB of the input signal level corresponding to the calibration sound pressure level on the reference level range. Record at least a 30-second sample of the signal. Note the input signal level.
3. Play back the recorded test signal to a one-third octave band spectrum analyzer and note the time-averaged output signal level in the band containing the calibration check frequency.
4. Repeat steps (1) through (3) for recordings of sinusoidal input signals at the nominal one-third octave midband frequencies from 50 Hz to 12.5 kHz. For each frequency, the level of the input signal should be the same as that used for the recording of the input signal at the calibration check frequency.
5. The frequency response in the upper part of the passband of the 10 kHz filter may be evaluated by the procedure described above by recording additional input signals at frequencies spaced at 1/24th octave intervals between the 10 kHz midband frequency and the 11.2 kHz upper bandedge frequency. The following sequence of test frequencies is recommended: 10 kHz, 10.3 kHz, 10.6 kHz, 10.9 kHz, and 11.2 kHz.
6. Determine the relative frequency response of the DUT, in decibels, from the one-third octave band levels of the output signals minus the level of the output signal in the one-third octave band containing the calibration check frequency. Resolution to the hundredth of a decibel is recommended for reporting the measurements of output signal levels.

8.3.4.4 Results

A graphical presentation of the relative frequency response should be created. The plot should provide sufficient resolution to clearly determine conformance to the performance specification. Relative frequency response should be plotted on the Y-axis and nominal one-third octave midband frequency on the X-axis. The calibration check frequency and the input signal level should be stated in the figure title along with other relevant information.

A tabular presentation of the relative frequency response data may be submitted instead of, or as a supplement to, the graphical presentation. The table should list the frequency of the input signals and the corresponding output signal level relative to the output signal level at the calibration check frequency.

Figure 6 provides an example of a graphical presentation for the frequency response of a DUT. For this example, the calibration check frequency was 1 kHz. The plot indicates that the relative frequency response did not exceed the specified tolerance limits over the range of one-third octave midband frequencies from 50 Hz to 12.5 kHz.

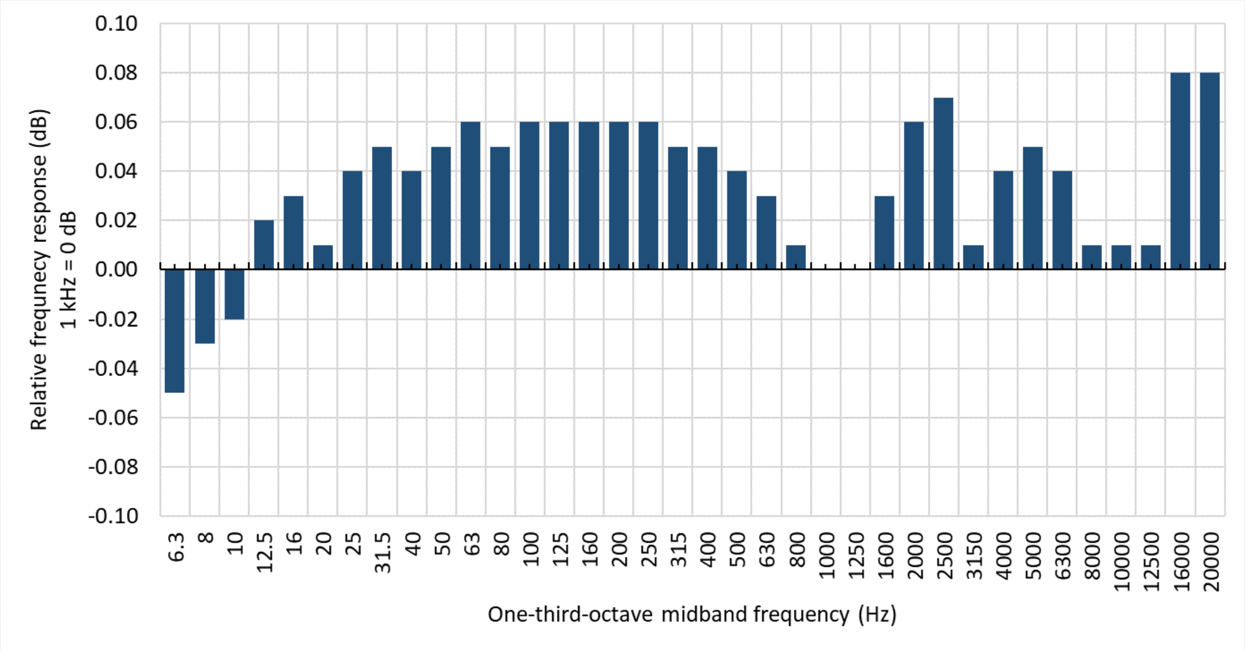

Figure 6. Relative frequency response on the reference level range for a DUT. An input signal level of 114 dB, at a frequency of 1 kHz, was referenced to an output level of 0 dB. The plot indicates a deviation < 0.11 dB across the bandwidth of interest.

8.3.5 Inter-channel crosstalk

8.3.5.1 Objective

The primary contributing mechanisms to inter-channel crosstalk are determined by circuit design and the layout geometry of circuit elements, for example, stray capacitance and inductive coupling. Inter-channel crosstalk is typically a function of the frequency of the input signals, not the signal strength.

The objective of this test is to quantify the level of signal leakage from a signal-driven channel to the other un-driven channel(s) of a multi-channel DUT.

8.3.5.2 Performance Specification

It is recommended that the level of crosstalk suppression be at least 70 dB between a signal-driven channel and any un-driven channel at frequencies within the range of interest and between all input-signal channels intended for use. Although there is no formal specification stated in Part 36/Annex 16 regarding inter-channel crosstalk, this level of channel isolation should be considered sufficient in order to maintain the integrity of the linear operating range cited in section 8.4.1.2.

8.3.5.3 Test Guidance

1. Apply a 50Hz sinusoidal electrical signal to the analog input of the DUT. The input signal level should be 10 dB less than the upper boundary of the linear operating range on the reference level

range.

2. Apply a short-circuit termination to the analog input(s) of the un-driven channel(s).
3. Record at least a 30-second sample of the test signal to the DUT. Ensure that both the driven and un-driven channels are engaged in data collection.
4. Apply a 20 Hz-to-20 kHz bandpass filter to the analog output of the DUT and play back the signal from the driven channel and note the level of the output signal at the test frequency. If available, note the signal levels to the hundredth of a decibel, otherwise to the tenth of a decibel.
5. Repeat the play back of the recording and determine the level of the output signal from each un-driven channel.
6. For each un-driven channel in turn, reverse the input connections on the driven and un-driven channel and repeat steps 1 through 5.
7. Repeat the above process at test frequencies of 1 kHz, 10 kHz, and the calibration check frequency if it is not one of those previously tested.

8.3.5.4 Results

Table 11 shows the preferred format for presentation of the results of inter-channel crosstalk tests. If the DUT has more than two analog input channels, the table should show the minimum level of suppression of crosstalk between the channels. Separate tabulations of test results should be provided for each driven channel.

Table 11. Recommended format for test results of inter-channel crosstalk for a four-channel DUT

Input signal channel and minimum crosstalk suppression	**Output signal level** dB		
	Test frequency		
	50 Hz	**1000 Hz**	**10 kHz**
Driven channel 1	111.04	111.01	111.02
Un-driven channel 2	30.22	31.56	32.94
Un-driven channel 3	30.46	31.30	31.48
Un-driven channel 4	30.37	30.94	32.39
Minimum crosstalk suppression (dB)	−80.58	−79.45	−78.08
NOTE 1: Crosstalk level = output signal level from an un-driven channel minus the output signal level of the driven channel NOTE 2: Crosstalk is typically expressed as a negative value			

8.3.6 Self-generated noise

8.3.6.1 Objective

Evaluate the spectrum of the self-generated electronic noise of the DUT. Ensure that the spectrum of the self-generated noise is as expected, without anomalies, and will not influence recorded data in an unanticipated manner.

8.3.6.2 Performance Specification

There is no specification for the level or spectrum of self-generated noise. However, because the level of self-generated noise affects the lower boundary of a linear operating range and the level of self-generated noise can increase with time, it is advisable to check the self-generated noise of a DUT at least once a year.

8.3.6.3 Test Guidance

1. Apply a resistive termination to the analog input of the DUT and record at least 30 seconds of a "no signal" sample of self-generated noise.

   NOTE: The termination may place a "dummy" load, e.g., a 50-ohm resistor, on the analog input of the DUT to exercise the electronics of the DUT without adding the electronic noise of an external device.

2. Connect the DUT output to a spectrum analyzer. A one-third-octave-band analyzer is preferred.
3. Play back the "no signal" recording to the spectrum analyzer using an averaging time of at least 20 seconds, or the maximum averaging time the recorded sample will permit. Ensure that the input range of the spectrum analyzer is properly adjusted so that the self-generated noise of the analyzer is not confused with the self-generated noise from the DUT.
4. Store the resulting spectral image displayed by the analyzer. Label the stored spectral image as "Self-generated noise". Plot the level of the output signal on the Y-axis in decibels (dB) and plot frequency on the X-axis in hertz (Hz).

8.3.6.4 Results

Image capture options will vary with the signal analyzer used. An analyzer-generated image is preferred; however other suitable methods include, but are not limited to: detailed photographs of the analyzer display screen, printing a screen capture, converting numerical data to plot graphs using a spreadsheet application or programming platform, such as MATLAB.

Figure 7 is an example plot of self-generated noise from a DUT. The results are presented as one-third-octave-band signal levels covering the range of midband frequencies from 6.3 Hz to 20 kHz.

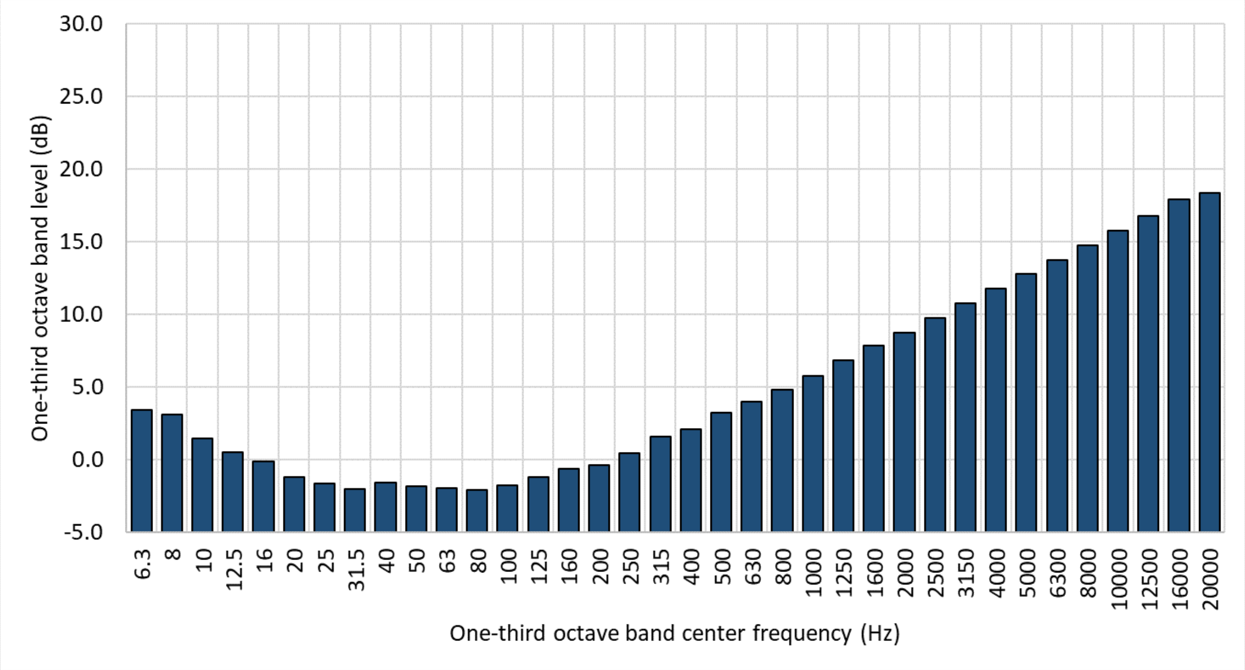

Figure 7. Graphic representation of DUT self-generated noise at nominal one-third octave band center frequencies

8.3.7 Level range steps (if applicable)

8.3.7.1 Objective

Given a constant input signal level, determine the change in DUT output level associated with each increment/decrement of the level range control.

8.3.7.2 Performance Specification

There is no performance specification for the level range control. However, in accordance with Part 36, Appendix A, Section A36.3.6.9 (and/Annex 16, Appendix 2, Section 3.6.9), range changes should operate in known intervals of decibel steps.

8.3.7.3 Test Guidance

1. Adjust the level range control of the DUT to the lowest setting (maximum attenuation).
2. Apply a 1 kHz sinusoidal test signal to the analog input of the DUT. Record a 30-second sample of the signal.

NOTE: Take special care to select a signal level which will be within the linear operating range of the DUT when set at both the minimum and maximum level range settings.

3. Connect the analog output of the DUT to a spectrum analyzer and play back the recorded test

signal. Note the indicated level.

4. Increment the DUT level range control to the next position while applying the 1 kHz test signal used in step 2. Record a 30-second sample.
5. Play back the recorded signal to the spectrum analyzer and note the indicated level.
6. Repeat steps 4 and 5 until all level range control settings have been tested.
7. Calculate the change in output level of the test signal corresponding to each increment of the level range control.

8.3.7.4 Results

Table 12 illustrates the recommended format for displaying the change in output level corresponding to each change in level range control setting. Include columns for level range control setting, measured DUT output level, and change in output level. Levels should be reported to 0.01 dB.

Table 12. Recommended format for results from level range control tests. Results indicate nominal 1 dB level range steps and a 20 dB range of gain/attenuation

DUT level range control setting	Measured DUT output level (dB)	Change in DUT output level (dB)
Start @ Minimum Level Range Setting	94.01	
+1	95.01	+01.00
+2	96.01	+01.00
+3	97.01	+01.00
+4	98.02	+00.99
+5	99.01	+01.01
+6	100.01	+01.00
+7	101.01	+01.00
+8	102.01	+01.00
+9	103.01	+01.00
+10	104.02	+00.99
+11	105.00	+01.02
+12	106.00	+01.00
+13	107.01	+00.99
+14	108.00	+01.01
+15	109.00	+01.00
+16	110.00	+01.00
+17	111.00	+01.00
+18	112.00	+01.00
+19	113.00	+01.00
+20	114.00	+01.00

8.3.8 DUT and legacy recorder comparison: recording and analysis of a transient noise source

8.3.8.1 Objective

Using the sound from an aircraft flyover or other transient sound source, evaluate the differences between the 0.5-second averaged one-third octave band sound pressure levels determined from recordings made on a recording device that has been previously validated for aircraft noise certification testing and on the DUT.

N*NOTE: This test is only intended for applicants that have systems that were previously approved by a certificating authority and wish to show that the system being validated exhibits similar performance with similar noise data. It should be considered "optional" in nature.*

8.3.8.2 Performance Specification

Differences greater than 1.0 dB between time-synchronized 0.5-second averaged one-third octave band sound pressure levels could indicate recorder anomalies or operational errors that may require additional testing.

8.3.8.3 Test Guidance

1. The test setup should utilize typical instruments, configurations, settings, and protocols as used by the applicant for aircraft noise certification testing.

NOTE: When it is not feasible to record the sound from an aircraft, e.g., when no aircraft noise tests are scheduled or for a new applicant, a transient sound such as that from the pass-by of an automobile or motorcycle may be used in lieu of the sound of an aircraft flyover.

2. Integrate the DUT into the measurement system. Ensure that the DUT and the aircraft noise certification validated recorder each receive identical input signals for acoustical data as well as time synchronization.

NOTE: Time synchronizing the recorded signals from the microphone is critical. The two recording devices may include the capability to record internally generated time signals or the signal from a time-code generator may be recorded on an unused channel of each recorder. An event-mark of some kind should be recorded on each recording near the time of closest approach of the aircraft or alternative noise source.

3. Using the applicant's standard procedure and usual settings for the level range controls, record a 30-second sample of the signal from the sound calibrator applied to the microphone.
4. Record the sound signal from an aircraft or alternative source on each recording device using the applicant's usual settings for the level range controls.
5. Process *the recorded signals through a* one-third octave-band spectrum analyzer that conforms to the specifications of IEC 61260-1 (2014) for class 1 performance. For each recording, calibrate the spectrum analyzer to the recorded calibration reference tone. Obtain 0.5-second averaged one-third octave-band sound pressure levels, in decibels, over

the range of midband frequencies from 25 Hz to 12.5 kHz. The same settings of the spectrum analyzer should be used to process the data from the two recording devices.

8.3.8.4 Results

Graphical presentations of the results are recommended; however, tabular data should be included in the event that graphical results are inconclusive. A diagram should also be included to illustrate the instruments used in the test setup and their connections.

Figure 8 shows the preferred format for presentation of the test results. The Y-axis indicates one-third octave band sound pressure levels (dB). The X-axis indicates midband frequencies (Hz). The scale for the Y-axis should be in whole decibels with grid spacing no greater than 2 dB. The scale for the X-axis should cover the range of mid-band frequencies. The title for the graph should indicate relevant information about the sound source and the relative time of observation. Additionally, graphical source data should be presented in a tabular format that clearly indicates midband frequencies and corresponding one-third octave band sound pressure levels for each recorder.

Results should be provided at the time of closest approach, however additional results are encouraged at, both, a few seconds before the time of closest approach, and a few seconds after the time of closest approach.

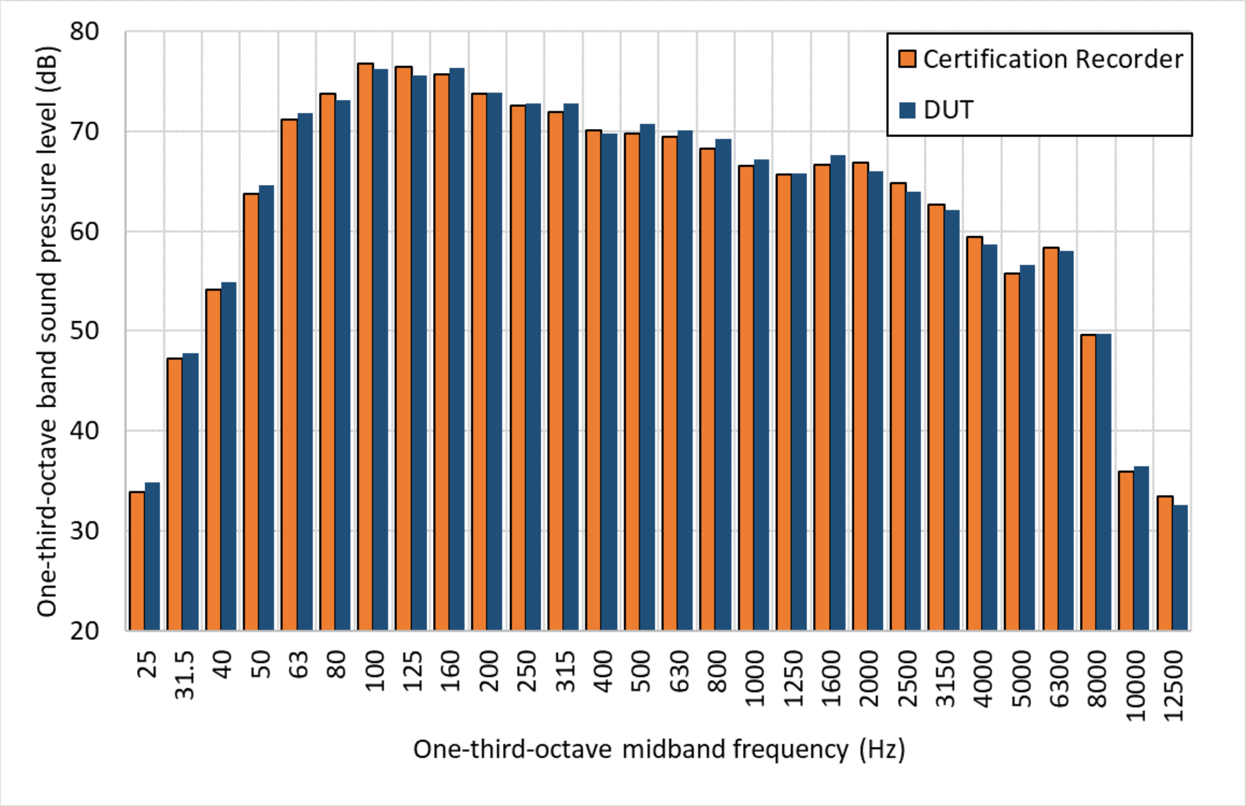

Figure 8. Comparison between spectra of the sound measured at 500 ft to the side of an aircraft in a level

flight and recorded on a validated recorder and on the DUT; plotted data are 0.5-second averaged one-third-octave-band sound pressure levels at the time of closest approach to the microphone

9. Setup and Operational Protocols

With the increasing complexity and flexibility of modern acoustic data collection and analysis systems, there are many ways to configure the system for various types of data, analysis, and end-uses. As such it is important to develop robust procedures and provide clear guidance to personnel who will be handling the data collection and analysis equipment for aircraft noise certification testing efforts. Providing detailed setup and operational protocols will help expedite the overall review of the data submittal and ensure that potential risks are mitigated, allowing for a comprehensive evaluation of the data collection and/or analysis system and its applied usage.

NOTE: Only functions used in the development of certified aircraft noise levels should be included, as the scope of Volpe's validation is limited to those functions. If information on secondary or diagnostic functions is desired to be included for the benefit of operators, those functions should be designated as non-certification, or otherwise isolated and differentiated from functions to be validated by Volpe.

9.1 System preparation, setup and field procedures

Please provide detailed user guidance indicating:

1. Steps taken to prepare the data collection/analysis system for aircraft noise certification testing;
2. Equipment deployment and step-by-step setup instructions for both hardware and software/firmware components, as applicable. Please include a diagram illustrating signal flow and system components (including make/model), interface connections, and associated cabling. Please indicate if wireless capabilities are employed anywhere in the data signal path;
3. Typical procedures for operating the system in the field including calibrations, system integrity checks, data quality checks and pre and post-detection noise floor characterization;
4. Data backup and archiving methods at the end of a test day;

The information requested above may be submitted as either a separate "Setup and Operational Protocols" report, or as additional sections or addenda to the "Data Collection and/or Analysis System Performance Report".

9.2 Other features and practical considerations

Not all features and functionalities pertaining to aircraft noise certification instrumentation systems are explicitly stated per Part 36/Annex 16, however, there are many aspects of the recording and analysis system that should be considered, in addition to the performance tests outlined in this document. Although this list does not account for all potential characteristics worthy of consideration, at a minimum, please provide a written description verifying that each of the following has been evaluated.

9.2.1 Level-range control

a. Does the recording/analysis system have "auto-ranging" capabilities that could toggle between level ranges during data collection? Such functionalities should be disabled since they may inadvertently change the system's noise floor and linear operating range.

b. Are separate level range controls provided for each channel input, e.g., by means of separate attenuators with decibel steps, or is one level range control used to adjust the sensitivity of all inputs?

9.2.2 Unintentional changes to settings

a. Does the recording/analysis system have safeguards against making accidental changes to important settings or features? Safe guards may be hardware based, such as locking panel controls or software based, such as disabling or "graying out" capabilities that may be incongruous with aircraft noise certification data collection and analysis.

b. Are there streamlined procedures for settings configuration and work flow or does the recording/analysis system interface require active control over its setup, parameters and operation? For example, can settings be pre-configured or loaded from a file and can operation be reduced to a minimum of controls that must be managed during data collection?

9.2.3 Low-power characteristics

a. Is battery power intended to be used for aircraft noise certification testing? If so, what is nominal run-time using the anticipated battery during normal operation?

b. Is there a clear low-power indicator providing sufficient warning to complete current data collection, shut-down and swap out batteries?

c. Is there any measurable degradation of data quality or change in recording/analysis system behavior under low-power conditions?

d. What happens if power is abruptly lost? Will there be data loss or will data be saved up until the point of power loss?

9.2.4 Data security

a. Is there redundancy built into the recording/analysis system, i.e., is a data "back-up" being captured at the time of data collection. For example, is data recorded simultaneously to both an internal hard disk drive and flash media?

b. Is data collected and stored at a centralized control station/computer or are there independent recording "nodes" that store data locally until it is retrieved at the end of a measurement day?

c. Are there protocols for backing up data at the end of each measurement day?
d. How difficult is it to accidentally delete, corrupt or record over test data? Are there sufficient warnings generated by the recording/analysis system to prevent such an occurrence?
e. Is the total recording time based on storage media size, number of channels and data resolution known? Is a warning generated if data storage capacity is approached?
f. Does the maximum sampling rate have any dependency on how full the storage is?

9.2.5 Time synchronization

a. Please identify the “master time source” and how it provides timing information to the recording/analysis system, e.g., internal oscillator disciplined via GPS-enabled time code generator?
b. If not already described in operational protocols, please provide details of time synchronization methods between acoustics data, aircraft positioning information, and other ancillary data, such as meteorological data.
c. Does the system continuously timestamp data or is time data indicated only at the beginning or end of file writing? Can the year, month, and day as well as an indication of the time of recording be displayed on playback?

9.2.6 Practical considerations

a. Environmental factors - is the recording/analysis system tolerant to harsh environ-mental factors, such as heat, cold, dust, humidity, vibration, or shock? Are the display screen(s) easily viewable in bright sunlight?
b. Input metering and other indicators - are input signal-level meters and other key parameters easy to view and clearly labeled in user interface?
c. Number of channels or tracks - how many channels or tracks are required for the anticipated data collection? Can aircraft noise signals be recorded simultaneously on all channels without a performance compromise?
d. Unique features - are there any unique features that may be designed for certain market segments, but which should never be used for aircraft noise-certification testing? For example, on-board processors or effects such as; automatic-gain-control, dynamic compression, reverberation, editing features, and pitch manipulation.

10. Checklist for Test Report

The test report should document all performance-relevant information including:

1. Hardware components of system (make, model and firmware revision);
2. Software components of system (including user-developed software, plugins, identification of source, version numbers, development platform/environment, etc.);
3. Diagram or description of system components and logical flow of operations;
4. Manufacturer's spec sheets (for commercially-available components);
5. System configuration to be validated:
    a. Number of simultaneous channels;
    b. Bandwidth (per channel), Hz (over range of nominal center frequencies);
    c. Bit-depth (per channel);
    d. Spectrum output interval, ms;
    e. Filter design octave frequency ratio (Base 2 or Base 10);
    f. Time-averaging mode (Linear or Exponential);
    g. Averaging time-period, seconds;
    h. Averaging time-constant, seconds;
    i. Filter design type;
    j. Media type;
    k. Data format(s);
    l. Power source (AC mains, batteries and type, etc.);

If applicable:

1. Data demonstrating analyzer conformance;
    a. Analyzer IEC61260-1 (2014) conformance (class 0, 1, 2, or previous version of standard, or alternate standard, i.e., ANSI S1-11 and Type);
    b. Relative attenuation (filter response shape) within IEC61260 tolerances;
    c. Filter Integrated Response ("bandwidth error");
    d. Real-time operation;
    e. Summation of output signals;
    f. Output resolution equal to or better than 0.1 dB;
    g. Linear time integration within ±5ms of 500ms (if used);
    h. Slow exponential time interval within ±5ms of 500ms (if used);
    i. Slow exponential time averaging rising/falling response;
    j. Data loss < 5ms per 500 ms sample;
    k. Response @ center frequencies, 50 Hz – 10 kHz within ±1.5 dB;

2. Data demonstrating recording/playback system conformance;
    a. Amplitude linearity;
    b. Anti-aliasing;
    c. Analog anti-aliasing filter prior to digitization;
    d. Frequency response;
    e. Quantify level range steps (if applicable);
    f. Maximum input signal / Overload indicator and characteristics;
    g. Full-scale identification;
    h. Noise floor;
    i. Inter-channel crosstalk;
    j. Environmental sensitivity/stability;
    k. Power supply check;

3. Applicant-generated documentation of setup and operation protocols

11. Submittal of Test Report

The test report should be submitted as an e-mail attachment sent to:

David.Read@dot.gov and;
Chris.Cutler-Wood@dot.gov

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