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AES standard method for digital audio engineering - Measurement of digital audio equipment

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AES standard method for digital audio engineering — Measurement of digital audio equipment

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Abstract

This standard provides methods for specifying and verifying the performance of medium-to-high performance digital audio equipment. It comprises an exhaustive list of measurements applicable to digital audio equipment.

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Foreword

[This foreword is not a part of *AES standard method for digital audio engineering — Measurement of digital audio equipment*, AES17-1998]

This document has been prepared by the SC-02-01 Working Group on Digital Audio Measurement Techniques of the SC-02 Subcommittee on Digital Audio of the Audio Engineering Society Standards Committee. It is a revision of AES17-1991. With the permission of AESSC, it also had been independently released by ANSI Accredited Standards Committee S4 as ANSI S4.51-1991.

Discussions on the revision project, AES17-R, began in the autumn of 1995. Proposals for revision have been discussed at five subsequent open working group meetings and over the working group reflector, SC_02_01@aessc.aes.org. The call for comment on its draft was published 1997-10-09 on http://www.aes.org/standards and was distributed with the *Journal of the Audio Engineering Society*, vol. 45, no. 11.

The following individuals contributed to the preparation of the 1991 edition of this document: Robert Adams, Richard Cabot, Louis Fielder, David Haynes, and Tomlinson Holman. The revision was prepared by R. Cabot based on the working group discussions.

Richard Cabot, Chair, SC-02-01
1998-03

Foreword to 2015 revision

[This foreword is not part of AES17-2015, *AES standard method for digital audio engineering - Measurement of digital audio equipment*.]

This document substantially revises and updates AES17-1998, *AES standard method for digital audio equipment - Measurement of digital audio equipment*. It includes measurements using more up-to-date measurement tools, and includes annexes describing advanced measurement methods for production testing, and frequency-domain and window-width filters.

The members of the writing group that developed this document in draft are: R.C. Cabot, I. Dennis, T. Duffy, J. Emmett, B. Katz, T. Kite, C. Lacinak, T. Lund, J.G. McKnight, H. Morfett-Jones, J. Novick, M. Poimboeuf, B. Putzeys, P. Soper, J. Woodgate, M. Yonge.

Tom Kite, Chair, SC-02-01
2015-07

Foreword to 2020 revision

[This foreword is not part of AES17-2020, *AES standard method for digital audio engineering - Measurement of digital audio equipment*.]

This document clarifies the definition of levels, the units FS and dBFS.

Jayant Datta, Chair, SC-02-01
2020-11

Note on normative language

In AES standards documents, sentences containing the word “shall” are requirements for compliance with the document. Sentences containing the verb “should” are strong suggestions (recommendations). Sentences giving permission use the verb “may”. Sentences expressing a possibility use the verb “can”.

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AES standard method for digital audio engineering - Measurement of digital audio equipment

0 Introduction

This standard provides methods for specifying and verifying the performance of medium- to high-performance digital audio equipment.

Many tests are very similar to those used for testing analogue equipment. However, because of the unique requirements of digital audio equipment and the effects of its imperfections, additional tests are needed.

The characteristics of voice-grade digital audio EUTs are sufficiently different from those of high-performance equipment that some of the test levels and frequencies specified in this document may need to be revised for these applications. Low bit-rate coders are an example of EUTs that require additional test techniques. The nature of such coders dictates that the test methods be based on psychoacoustic models which can predict subjective performance. However, the techniques described here should still be informative for such systems.

Another caveat concerns digital EUTs which purposely modify the time-domain characteristics of the audio signal, such as pitch shifters and reverberators. Many of the tests in this standard assume that the frequency spectrum of the output signal is substantially the same as that of the input signal. Also, high-level interfering signals (as would be encountered with reverberators) have not been considered.

1 Scope

This standard specifies basic measurement methods of medium- to high-performance digital audio equipment.

It includes definitions, and measuring conditions and methods applicable to professional equipment.

This standard does not consider:

− measurement of low-quality audio devices,

− measurement of low-bit-rate audio devices (‘sub-band’ or ‘perceptual’ coding devices),

− measurement of devices which significantly modify time or frequency characteristics of the signal, such as pitch shifters or reverberators,

− measurement of signals from analogue input to analogue output, beyond the most general,

− EMC and safety related testing.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ITU-R BS.468-4, *Measurement of audio-frequency noise voltage in sound broadcasting*. International Telecommunication Union, Geneva, Switzerland.

IEC 61260-1, *Electroacoustics - Octave-band and fractional-octave-band filters.* International Electrotechnical Commission, Geneva, Switzerland.

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3 Terms and definitions

For the purposes of this standard, the following definitions apply.

3.1
EUT
Equipment under test

3.2
Folding frequency
one-half the sampling frequency of the digital system

NOTE The folding frequency defines the maximum upper band-edge frequency. A signal applied to the input whose frequency is above the folding frequency is subject to aliasing. For EUTs which operate at multiple simultaneous sampling frequencies, the sampling frequency to be considered is the lowest sampling frequency in the signal path.

3.3
Upper band-edge frequency
highest signal frequency to be measured (see 4.3)

NOTE 1 The non-ideal behaviour of anti-aliasing filters and reconstruction filters in the EUT leads to the upper band-edge frequency being lower than the folding frequency.

NOTE 2 A higher upper band-edge frequency may be used for higher sampling rates.

3.4
Passband
frequency band from 20 Hz to the upper band-edge frequency

3.5
Alias products
signal components that appear in the passband, caused by input signals above the folding frequency

3.6
Image products
signal components that appear above the passband, caused by input signals below the folding frequency

3.7
Input word length
maximum number of bits in a digital word which can be applied to the digital input of an EUT for which none of the bits is ignored

NOTE The input word length of an EUT determines the correct dither level in the test signal.

3.8
Output word length
maximum number of bits in a digital word transmitted by the digital output of an EUT for which all bits have values that vary over time

3.9
Positive digital full scale
highest value code in the digital representation

NOTE In 24-bit two's complement, this code is $7FFFFF_{16}$.

3.10
Negative digital full scale
lowest value code in the digital representation

NOTE In 24-bit two's complement, this code is 800000_{16}.

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3.11
Least significant bit
LSB
smallest change that can be represented in a digital word

3.12
Levels

NOTE All levels defined in the standard are based on rms values of sine waves.

3.12.1
Full-scale level
level of a dc-free 997-Hz sine wave whose undithered positive peak value is positive digital full scale, leaving the code corresponding to negative digital full scale unused

NOTE 1 Full-scale level may be reported as “1,0 FS” or “0 dBFS”.

NOTE 2 All test signals defined in this document are dithered as described in section 5.1.3. For dithered signals at full-scale level, the level should be reduced so that the dithered positive peak value just reaches positive digital full scale.

3.12.2
Signal level, FS
rms signal level expressed as a fraction of full-scale level (see 3.12.1)

NOTE 1 Sine waves whose peak reaches digital full scale will read 1,0 FS.

NOTE 2 Levels reported in FS are always rms. It is invalid to use FS for non-rms levels.

NOTE 3 Because the definition of full scale is based on a sine wave, the level of signals with a crest factor smaller than that of a sine wave may exceed 1,0 FS. In particular, square-wave signals may reach +1,41 FS. Tilt or overshoot introduced by signal processing may cause clipping of signals above 1,0 FS. The level of signals with a crest factor larger than that of a sine cannot reach 1,0 FS.

3.12.3
Decibels full scale
dBFS
rms level expressed in decibels relative to full-scale level. dBFS is computed from FS using the relation

”Level in dBFS” = 20 lg (“level in FS”)

NOTE 1 Sine waves whose peak reaches digital full scale will read 0 dBFS.

NOTE 2 Levels reported in dBFS are always rms. It is invalid to use dBFS for non-rms levels.

NOTE 3 Because the definition of full scale is based on a sine wave, the level of signals with a crest factor smaller than that of a sine wave may exceed 0 dBFS. In particular, square-wave signals may reach +3,01 dBFS. Tilt or overshoot introduced by signal processing may cause clipping of signals above 0 dBFS. The level of signals with a crest factor larger than that of a sine cannot reach 0 dBFS.

3.13
Dither signal
noise signal added to a signal before quantization to linearize the quantizer

NOTE The correct dither has a triangular probability density function, with a maximum level of ±1 LSB.

3.14
Digital zero
signal consisting only of dither at the appropriate level for the word length

3.15
Jitter susceptibility

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effect on EUT performance of jitter present on the signal or clock reference inputs

3.16
Crest factor
ratio of the absolute peak level of a signal to its time-averaged rms level

3.17
Code
value of a digital audio sample. A complete set of codes describes the entire dynamic range of the coded audio

4 Measurement conditions

4.1 Environmental

All tests in this standard shall be performed at an ambient temperature of (23 ± 5) °C unless otherwise specified by the manufacturer. When specifications are listed for an EUT with a temperature range of operation, these specifications are assumed to be valid over the entire range, and shall be verified at the rated limits.

4.2 Power supply

4.2.1 EUTs powered directly from the mains

Power-line (mains) voltage shall be set within 2 % of the nominal value listed on the EUT. If a range of values is given, the specifications are assumed to be valid over the range, and shall be verified at the rated limits.

Power-line frequency shall be set within 1 % of the nominal value listed on the EUT. If a range of values is given, the specifications are assumed to be valid over the range, and shall be verified at the rated limits.

4.2.2 EUTs powered from the mains via an external power supply

The external power supply shipped with the EUT shall be used. The power line conditions listed in 4.2.1 shall apply.

4.2.3 EUTs using battery power

One of the following power sources shall be used:

- A battery of the type required or recommended for the EUT; or
- A dc power supply with a peak-to-peak ripple content of less than 0,5 % of the nominal dc supply voltage.

4.3 Bandwidth

An EUT using a 44,1 kHz or 48 kHz sampling frequency shall have an upper band-edge frequency of 20 kHz.

An EUT which uses a sampling frequency other than 44,1 kHz or 48 kHz may have an upper band-edge frequency defined by the manufacturer. This frequency, if different from 20 kHz, shall be stated in the manufacturer's specifications.

If an upper band-edge frequency specified by the EUT manufacturer is used, it shall be the same for all tests.

4.4 EUT settings

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

The normal source impedance for terminating an analogue input shall be 50 Ω, unless otherwise specified by the manufacturer. Measurements which use an input termination different from 50 Ω shall be so noted.

If any emphasis is provided, it shall be set to the manufacturer’s recommended position. This setting shall be clearly indicated in the specifications. If a recommended position is not stated by the manufacturer, emphasis

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shall not be used. If desired, some measurements may be repeated with other settings. Such measurements shall be clearly indicated as supplementary, and shall be reported in addition to the results of the same tests performed using the recommended position.

If the EUT includes limiters, compressors, or other means to affect signal dynamics, they shall be disabled. The results of any additional tests on these features shall be reported separately.

4.5 EUT preconditioning

The EUT shall be connected under normal operating conditions for the preconditioning period specified by the EUT manufacturer before any measurements are performed. This condition is intended to allow the EUT to stabilize. If no preconditioning period is specified by the manufacturer, a 5 minute period shall be assumed. The EUT manufacturer should state if operational requirements preclude preconditioning.

If power to the EUT is interrupted during the measurements, enough time shall be allowed for the EUT to stabilize again before resuming.

5 Measurement equipment

5.1 Signal generator

5.1.1 Overview

Depending on the nature of the EUT, either an analogue or digital generator may be required. This clause defines their characteristics.

5.1.2 Output impedance

Unless otherwise specified, the analogue signal generator shall have an output impedance of 50 Ω or less. The digital signal generator shall have an output impedance appropriate for the physical layer to which it connects.

5.1.3 Dither signal

For measurements where the stimulus originates in the digital domain, the test signals shall be dithered. When the stimulus is applied in the analogue domain, the inclusion of dither shall be the responsibility of the EUT manufacturer, and shall not be supplemented during testing.

The dither signal shall be a random or pseudorandom sequence having a triangular probability density function and a peak level of ±1 LSB of the digital audio input word length (see 3.7). The dither power shall be constant per unit bandwidth to the upper band-edge frequency.

> NOTE Such a dither signal may be generated by subtracting two random or pseudorandom numbers whose values are uniformly distributed between 0 LSB and 1 LSB.

If a pseudorandom signal is used, its repetition interval shall be at least as long as the measurement interval of the meters used. It shall be generated from a maximum-length polynomial of greater than two terms. The samples should be spaced by several shifts of the polynomial to reduce sample-to-sample correlation. Care should be taken to avoid polynomials that create large short-term energy variation, or that produce substantial asymmetry in the probability distribution when low-pass filtered.

5.1.4 Accuracy

The analogue and digital signal generators shall provide the ability to set frequency with an accuracy of at least ±0,05 %.

The analogue signal generator shall have a level accuracy of at least ±(0,2 dB + 3 μV) at 1 kHz, and at least ±(0,3 dB + 3 μV) from 20 Hz to the upper band-edge frequency.

The digital signal generator shall have a level accuracy of at least at least ±(0,01 dB + 0,5 LSB) from 20 Hz to the upper band-edge frequency.

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5.2 Signal analyzer

5.2.1 Overview

Depending on the nature of the EUT, either an analogue or digital analyzer may be required. This clause defines their characteristics.

Some measurements require one or more standard filters (the filter requirements are noted in each measurement). The standard filters are described in the following clauses.

5.2.2 Input impedance

Unless otherwise specified, the analogue signal analyzer shall have an input impedance of 100 kΩ or greater. The input capacitance shall be 500 pF or less. The digital signal analyzer shall have an input impedance appropriate for the physical layer to which it connects.

5.2.3 Level meter

Level meters shall be true root-mean-square (rms) responding devices with an accuracy of at least ±0,25 dB at 1 kHz. This accuracy shall be maintained for signals having a crest factor of 5 or less. RMS-calibrated average or peak-responding devices are not acceptable. If the accuracy specification in 5.2.11 requires better performance than this, then 5.2.11 shall take precedence.

Level meters shall integrate the signal for a minimum of 25 ms to ensure that enough codes are exercised in the EUT. At low frequencies the integration time shall be increased to ensure that at least one full cycle of the test signal is measured.

5.2.4 Phase meter

Phase meters shall have a minimum accuracy of ±1° at 1 kHz, and ±5° at 20 kHz. This accuracy shall be maintained for any signal whose rms sum of harmonic, non-harmonic, and spurious components does not exceed 1 % of the total signal level.

5.2.5 Standard low-pass filter

For an upper band-edge frequency of 20 kHz, the standard low-pass filter shall have the following characteristics:

- Passband response deviation: ≤ ±0,1 dB, 20 Hz ≤ f ≤ 20 kHz
- Stopband attenuation: ≥ 60 dB, f > 24 kHz

For an upper band-edge frequency other than 20 kHz, the standard low-pass filter shall have the following characteristics:

- Passband response deviation: ≤ ±0,1 dB, 20 Hz ≤ f ≤ upper band-edge frequency
- Stopband attenuation: ≥ 60 dB, f > (sampling frequency – upper band-edge frequency)

5.2.6 Standard high-pass filter

For an upper band-edge frequency of 20 kHz, the high-pass filter shall have the following characteristics:

- Passband response deviation: ≤ ±0,5 dB, 26 kHz ≤ f ≤ 200 kHz
- Stopband attenuation: ≥ 40 dB, 20 Hz ≤ f < 20 kHz

For an upper band-edge frequency other than 20 kHz, the high-pass filter shall have the following characteristics:

- Passband response deviation: ≤ ±0,5 dB, 1.3 times upper band-edge frequency ≤ f ≤ 200 kHz
- Stopband attenuation: ≥ 40 dB, 20 Hz ≤ f ≤ upper band-edge frequency

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5.2.7 Standard weighting filter

The standard weighting filter shall conform to ITU-R BS.468-4, with an additional gain of -5,63 dB. (This puts the unity gain frequency at 2 kHz.) This gain-shifted response is known as the "CCIR-RMS" filter. Table 1 shows the required response and tolerance of the filter.

Measurements made with this filter shall be denoted "[unit] CCIR-RMS", where [unit] is the appropriate unit for the measurement.

See also: 5.5.2 for more information on units.

Table 1 - CCIR-RMS weighting filter response

Frequency (Hz)	Gain (dB)	Tolerance (dB)
31,5	-35,5	±2,0
63	-29,5	±1,4
100	-25,4	±1,0
200	-19,4	±0,85
400	-13,4	±0,70
800	-7,5	±0,55
1 000	-5,6	±0,50
2 000	0,0	±0,50
3 150	3,4	±0,50
4 000	4,9	±0,50
5 000	6,1	±0,50
6 300	6,6	±0,01
7 100	6,4	±0,20
8 000	5,8	±0,40
9 000	4,5	±0,60
10 000	2,5	±0,80
12 500	-5,6	±1,2
14 000	-10,9	±1,4
16 000	-17,3	±1,6
20 000	-27,8	±2,0
31 500	-48,3	+2,8; -∞

5.2.8 Standard notch filter

The standard notch filter shall have a quality factor Q of at least 1,2 and not more than 3, where Q is defined as the ratio of the center frequency to the difference between the -3 dB frequencies. Multistage notch filters are acceptable if their combined Q measures within these limits using this definition.

5.2.9 Standard band-pass filter

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

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

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

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See also: 5.2.11 for more information on the required gain accuracy of the standard band-pass filters.

5.2.10 Frequency-domain band-pass filters

NOTE 1 Frequency-domain band-pass filters are able to isolate tones better than conventional time-domain filters. They are also known as *window-width filters*, because it is possible to create band-pass filters with them whose bandwidth is equal to the number of bins in the main lobe of the transform window.

NOTE 2 Typically, frequency-domain filters are implemented by Fast Fourier Transform (FFT), an analysis method also used by FFT analyzers. A measurement that specifies a frequency-domain filter therefore implies the use of an FFT analyzer.

Frequency-domain band-pass filters are specified for certain measurements for which a band-pass filter with a very narrow bandwidth is needed to obtain accurate results. They may also be used to provide better noise rejection than the standard band-pass filter for measurements which do not depend on the specific shape of the band-pass filter used. The filter must still meet the gain accuracy requirements of 5.2.11.

The combination of sample rate, acquisition length, and window type shall be sufficient to achieve the bandwidth needed for the measurement. The bandwidth shall be specified in each measurement.

See also: Annex B for more information.

5.2.11 Accuracy

For all measurements in this standard, unless otherwise specified, the measurement equipment shall have an accuracy in the parameter being measured of at least three times better than the specification being verified. Table 2 contains some examples.

Table 2 - Measurement accuracy - Examples

Parameter	EUT figure	Measurement equipment figure	Worst-case error
Noise, 20 Hz to 20 kHz, rms	10 µV	<3,3 µV	0,53 µV
THD+N ratio, 20 kHz BW	-95 dB	<-104,5 dB[1]	0,45 dB
Gain flatness, 20 Hz to 20 kHz	±0,03 dB	<±0,01 dB	±0,01 dB

NOTE ([1]) This figure is computed either by converting to a linear ratio, dividing by 3, and converting back to dB; or by noting that 20 lg(1/3) = -9,54 dB.

5.3 Scope of measurements

Some of the methods in the standard specify a range and density of settings over which to make the measurement. For example, the frequency response measurement in 6.2.3 states:

"The frequency of the test signal shall be varied from 20 Hz to the upper band-edge frequency in steps of no more than one octave."

This should be taken as the minimum requirement to achieve acceptable results. It is permissible to use a wider range, or a higher point density, if desired.

See also: 5.4 for a table of standard octave-spaced and third-octave-spaced test frequencies.

Measurements indicated "**Optional**" are not required. If they are made, they shall be performed in addition to the recommended measurements, not instead of them.

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