ANSI S1.26-1995
(ASA 113-1995)

Revision of
ANSI S1.26-1978 (R1989)

AMERICAN NATIONAL STANDARD

METHOD FOR CALCULATION OF THE ABSORPTION OF SOUND BY THE ATMOSPHERE

ANSI S1.26-1995 (ASA 113-1995)

Accredited Standards Committee S1, Acoustics

Standards Secretariat
Acoustical Society of America
120 Wall Street, 32nd Floor
New York, New York 10005-3993

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Method for Calculation of the Absorption of Sound by the Atmosphere

Secretariat

Acoustical Society of America

Approved: 24 July 1995

American National Standards Institute, Inc.

Abstract

This Standard provides the means to calculate atmospheric absorption losses of sound from any source, moving or stationary, for a wide range of meteorological conditions. The atmosphere is assumed to be still, homogeneous moist air of normal composition. Non-homogeneous atmospheres may be divided into horizontal layers within which homogeneous conditions may be assumed. Attenuation coefficients for pure-tone sounds are calculated by means of equations (or a table) over ranges of frequency, and the humidity, pressure, and temperature of the atmosphere. For sounds analyzed by fractional-octave-band filters (e.g., one-third-octave-band filters), alternative methods are provided in annexes to calculate the attenuation caused by atmospheric absorption from that specified for pure-tone sounds.

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Contents

Foreword

[This foreword is for information only and is not an integral part of ANSI S1.26-1995 *American National Standard Method for Calculation of the Absorption of Sound by the Atmosphere* (ASA Catalog No 113-1995)]

This American National Standard, like the original version first published in 1978, provides an analytical method to calculate absorption losses experienced by sound from any source propagating through the atmosphere. This issue of ANSI S1.26-1995 supersedes ANSI S1.26-1978. The calculation method was modified as a result of additional data on absorption of sound in air and better understanding of vibrational relaxation of nitrogen molecules than were available for the 1978 issue.

This standard is the American National Standard counterpart of International Standard ISO 9613-1:1993, "Acoustics – Part 1: Calculation of the absorption of sound by the atmosphere." The technical requirements in this American National Standard are identical to those in ISO 9613-1.

This standard contains five informative annexes.

Annex E in this American National Standard is not contained in ISO 9613-1. This new annex describes a practical method to compute the atmospheric attenuation applicable to fractional-octave-band sound pressure levels measured at a large distance from a sound source or under highly absorptive conditions, or a combination of distance and absorptive conditions. Also, the scope of this American National Standard is not limited to sound propagation outdoors as is ISO 9613-1, but also includes room acoustics.

This standard was developed under the jurisdiction of Accredited Standards Committee S1, Acoustics, which has the following scope:

> *Standards, specifications, methods of measurement and test, and terminology, in the fields of physical acoustics, including architectural acoustics, electroacoustics, sonics and ultrasonics, and underwater sound, but excluding those aspects which pertain to safety, human tolerance and comfort*

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Working Group S1-2, Attenuation of Sound in the Atmosphere, which assisted Accredited Standards Committee S1, Acoustics, in the preparation of this Standard, had the following membership:

A H. Marsh, *Chairman*

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Suggestions for improvement will be welcomed. Send suggestions for improvement to Accredited Standards Committee S1, Acoustics, in care of the ASA Standards Secretariat, 120 Wall Street, 32nd floor, New York, New York 10005-3993. Telephone: +1 212 248 0373; FAX: +1 212 248 0146.

American National Standard

Method for Calculation of the Absorption of Sound by the Atmosphere

1 Scope

1.1 This Standard specifies an analytical method to calculate the attenuation of sound as a result of atmospheric absorption for a variety of meteorological conditions when the sound from any moderate-amplitude source propagates through the atmosphere. The calculation method of the Standard applies for molar concentrations of water vapor in the atmosphere from less than 0.005 percent to greater than 5 percent and for ratios of the frequency of the sound to the atmospheric pressure from as low as 4×10^{-4} Hz/Pa (40 Hz per atmosphere) to as great as 10 Hz/Pa (1 MHz per atmosphere).

1.2 For pure-tone sounds, attenuation, in decibels, owing to atmospheric absorption is specified by formulae in terms of an attenuation coefficient, in decibels per unit sound-propagation distance, as an analytical function of four variables: the frequency of the sound, and the temperature, humidity, and pressure of the atmosphere. Computed attenuation coefficients are provided in tabular form for ranges of the variables commonly encountered in prediction of outdoor sound propagation.

1.3 For wideband sounds analyzed by fractional-octave band filters (e.g., one-third octave band filters), an approximate method is provided for calculating the attenuation owing to atmospheric absorption from that specified for pure-tone sounds at the midband frequencies. The spectrum of the sound may be wideband with no significant discrete-frequency components or it may be a combination of wideband and discrete frequency sounds.

1.4 This Standard applies to an atmosphere with uniform meteorological conditions and to a stratified atmosphere in which the meteorological conditions may be considered to be uniform within layers. The procedures described in the Standard may be used to determine adjustments to be applied to measured sound pressure levels to account for differences between atmospheric absorption losses under different meteorological conditions. The calculation method may also be applied to assess the contribution of atmospheric absorption to the decay of sound pressure level in a reverberant sound field.

1.5 This Standard accounts for the principal absorption mechanisms present in an atmosphere devoid of significant fog or atmospheric pollutants. It does not cover sound attenuation by mechanisms other than atmospheric absorption such as wave divergence, refraction, scattering by turbulence, ground reflection, or non-linear propagation effects.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents listed below.

2.1 American National Standards

ANSI S1.11-1986 (R1993), American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters.

2.2 International Standards

IEC 1260:1995, Octave-band and fractional-octave-band filters.

ISO 2533:1975, Standard atmosphere.

ISO 9613-1:1993, Acoustics – Attenuation of sound during propagation outdoors - Part 1: Calculation of the absorption of sound by the atmosphere.

3 Reference atmospheric conditions

3.1 Composition

Atmospheric absorption is sensitive to the composition of the air, particularly to the varying concentration of water vapor. For clean dry air at sea level, for the purposes of this Standard, the molar concentrations, or fractional volumes, of nitrogen, oxygen, and carbon dioxide, rounded to three significant figures, are 0.781, 0.209, and 0.000314, respectively. For dry air, other minor trace constituents, which have no significant influence on atmospheric absorption, make up the remaining fraction. For atmospheric-absorption calculations, the standard molar concentrations of the principal constituents of dry air may be assumed to hold for altitudes to at least 50 km above mean sea level. On the other hand, the molar concentration of water vapor, which has a major influence on atmospheric absorption, varies widely near the ground and by nearly three orders of magnitude from sea level to an altitude of 20 km.

3.2 Atmospheric pressure and temperature

For purposes of this Standard, the reference atmospheric pressure, p_r, is that of the International Standard Atmosphere at mean sea level, namely 101.325 kPa; see ISO 2533. The reference air temperature, T_r, is 293.15 K (i.e., +20 °C) — the temperature at which the most-reliable data supporting this Standard were obtained.

4 Attenuation coefficients owing to atmospheric absorption for pure-tone sounds

4.1 Basic expression for attenuation

4.1.1 As a pure-tone sound propagates through the atmosphere over a distance s, the pressure amplitude p_t decreases exponentially, as a result of the atmospheric-absorption effects described in this Standard, from its initial value p_i in accordance with the decay formula for plane sound waves in free space

$$p_t = p_i \exp(-0.1151\,\alpha s) \qquad (1)$$

where sound pressures p_t and p_i are in pascals, distance s is in metres, α is the pure-tone sound-attenuation coefficient for atmospheric absorption in decibels per metre. From here on, for convenience, the shortened term, attenuation coefficient, will be used for α in place of the full description just given. In Eq. (1), the term exp(-0.1151 αs) represents the base e of Napierian logarithms raised to the exponent indicated by the argument in parentheses, and $0.1151 \approx 1/[10\ \lg(e^2)]$ nepers per decibel is included because attenuation coefficients are in decibels per metre, not nepers per metre.

4.2 Attenuation of sound pressure levels

Attenuation $\delta L_t(f)$, in decibels, owing to atmospheric absorption of the sound pressure level of a pure tone with frequency f, from the initial level at $s = 0$ to the level at distance s, is given by

$$\begin{aligned}\delta L_t(f) &= -10\ \lg(p_t^2 / p_i^2) \\ &= -10\ \lg[\exp(-0.1151\,\alpha s)]^2 = \alpha s \qquad (2)\end{aligned}$$

where the sound-attenuation coefficient α is a function of frequency and atmospheric conditions.

5 Calculation procedure for pure-tone attenuation coefficients

5.1 The variables

5.1.1 The primary acoustic and atmospheric variables, and their letter symbols, units, and unit symbols, are: (1) the frequency of the sound f (in hertz, unit symbol Hz), (2) ambient atmospheric temperature T (in kelvins, unit symbol K), (3) molar concentration of water vapor h (in percent, unit symbol %), and (4) ambient atmospheric pressure p_a (in kilopascals, unit symbol kPa).

NOTES

1 For a specific sample of moist air, molar concentration of water vapor is the ratio, expressed as a percentage, of the number of kilomoles (i e., the number of kilogram molecular weights) of water vapor to the number of kilomoles of moist air in the sample. The number of kilomoles of moist air is the sum of the number of kilomoles of dry air and water vapor By Avogadro's law, molar concentration of water vapor is also the ratio of the partial pressure of water vapor to the atmospheric pressure.

2 Molar concentrations of water vapor range from about 0.2% to 2% for commonly encountered atmospheric conditions at altitudes near mean sea level, but decrease to well below 0.01% at altitudes above 10 km.

5.2 The formulae

5.2.1 As described in annex A, attenuation owing to atmospheric absorption is a function of two vibrational relaxation frequencies, f_{rO} and f_{rN}, for oxygen and nitrogen, respectively. Values of f_{rO} and f_{rN}, in hertz, shall be calculated from

$$f_{rO} = \frac{p_a}{p_r}\left\{24 + \left[\frac{(4.04 \times 10^4 h)(0.02 + h)}{0.391 + h}\right]\right\} \tag{3}$$

and

$$f_{rN} = \frac{p_a}{p_r}\left(\frac{T}{T_r}\right)^{-1/2} \times \left(9 + 280 h \exp\left\{-4.170\left[\left(\frac{T}{T_r}\right)^{-1/3} - 1\right]\right\}\right) \tag{4}$$

5.2.2 The attenuation coefficient α, in decibels per metre, shall be calculated from

$$\alpha = 8.686 f^2 \left(\left[1.84 \times 10^{-11}\left(\frac{p_a}{p_r}\right)^{-1}\left(\frac{T}{T_r}\right)^{1/2}\right] + \left(\frac{T}{T_r}\right)^{-5/2} \times \left\{0.01275\left[\exp\left(\frac{-2239.1}{T}\right)\right]\left[\frac{f_{rO}}{f_{rO}^2 + f^2}\right] + 0.1068\left[\exp\left(\frac{-3352.0}{T}\right)\right]\left[\frac{f_{rN}}{f_{rN}^2 + f^2}\right]\right\}\right) \tag{5}$$

Values for relaxation frequencies f_{rO} and f_{rN} in Eq. (5) shall be calculated by use of Eqs. (3) and (4).

5.2.3 In Eqs. (3) to (5), f, p_a, T, and h represent the variables specified in 5.1; p_r and T_r are the reference atmospheric pressure and temperature specified in 3.2.

5.2.4 Equation (5) is a condensed form suitable for computations. Formulae for the contributions from the individual physical mechanisms are given in annex A.

5.3 Computation of attenuation coefficients

5.3.1 Equations (3) to (5) are all that are needed to calculate the pure-tone attenuation coefficient for atmospheric absorption for selected values of the variables. Although air temperature and atmospheric pressure data may not be supplied in the units of measure given in 5.1, conversion factors are readily available to convert the given unit to kelvins or kilopascals, respectively. Humidity data, on the other hand, are rarely supplied in terms of molar concentration of water vapor. Annex B provides information on conversion of humidity data in terms of relative humidity or dewpoint to corresponding values of molar concentration.

5.3.2 Annex C describes the means by which the attenuation may be determined by use of the formulae of 5.2 for a pure-tone sound that propagates through a real, inhomogeneous atmosphere. Annexes D and E describe procedures for calculating the attenuation by atmospheric absorption when sounds are analyzed by fractional-octave-band filters.

5.4 Tabular values of attenuation coefficients

5.4.1 Table 1 lists pure-tone attenuation coefficients calculated by use of Eqs. (3) to (5) for selected values of air temperature, relative humidity, and frequency, at the reference pressure of one standard atmosphere (101.325 kPa). The unit is decibels per kilometre for convenience in applications to sound propagation over long pathlengths. Tabular values are presented to 3 significant figures.

5.4.2 Users of Table 1 should not interpolate between the entries, or extrapolate beyond the table range, but should utilize Eqs. (3) to (5) to calculate specific pure-tone attenuation coefficients for desired conditions.

5.4.3 Annex A describes a procedure that may be employed to determine attenuation coefficients for atmospheric pressures other than the reference atmospheric pressure in lieu of using the formulae in 5.2 and annex B.

NOTES

1 Frequencies shown in Table 1 are the nominal midband frequencies for one-third-octave-band fil-

ters in accordance with ANSI S1 11-1986 (or IEC 1260). However, attenuation coefficients in Table 1 were calculated for the exact midband frequencies f_m, in hertz, using the general expression for the N-th frequency band according to the base-10 system

$$f_m = f_0 (10^{3/10b})^N \qquad (6)$$

where the reference frequency, f_0, is 1 Hz, and 1/b is the bandwidth designator for a fractional-octave filter band, e g., 1/b = 1/3 for one-third-octave-band filters. For Table 1, index N ranged over the integers from +17 to +40, corresponding to nominal midband frequencies from 50 Hz to 10 kHz

2 Relative humidities given as column headings in Table 1 are with respect to saturation over a surface of liquid water at all temperatures; see annex B. Saturation vapor pressures were calculated from the formulae given in annex B.

6 Accuracy of calculated pure-tone attenuation coefficients for various ranges of the variables

6.1 Accuracy of ±5 percent

Accuracy of the calculated pure-tone attenuation coefficients computed by the method of this Standard is estimated to be ±5 percent for an air temperature of 293.15 K (+20 °C), an atmospheric pressure of one standard atmosphere (p_a = p_r = 101.325 kPa), molar concentration of water vapor from 0.2% to 2% (i.e., relative humidity from 10% to 100%), and frequency of the sound from 2 kHz to 15 kHz.

6.2 Accuracy of ±10 percent

Accuracy of the calculated pure-tone attenuation coefficients is estimated to be ±10 percent for variables within the following ranges:

- molar concentration of water vapor: 0.05% to 5%;
- air temperature: 253.15 K to 323.15 K (-20 °C to +50 °C);
- atmospheric pressure: less than 200 kPa (i.e., less than two atmospheres); and
- frequency-to-pressure ratio: 4×10^{-4} Hz/Pa to 10 Hz/Pa (40 Hz/atm to 1 MHz/atm)

6.3 Accuracy of ±20 percent

Accuracy of the calculated pure-tone attenuation coefficients for atmospheric absorption is estimated to be ±20 percent for variables within the following ranges:

- molar concentration of water vapor: 0.005% to 0.05% and greater than 5%;
- air temperature: 253.15 K to 323.15 K (-20 °C to +50 °C);
- atmospheric pressure: less than 200 kPa (less than two atmospheres); and
- frequency-to-pressure ratio: 4×10^{-4} Hz/Pa to 10 Hz/Pa

6.4 Accuracy of ±50%

Accuracy of the calculated pure-tone attenuation coefficients for atmospheric absorption is estimated to be ±50% for variables within the following ranges, which include environmental conditions encountered at altitudes up to 20 km:

- molar concentration of water vapor: less than 0.005%;
- air temperature: greater than 200 K (-73 °C);
- atmospheric pressure: less than 200 kPa (two atmospheres): and
- frequency-to-pressure ratio: 4×10^{-4} Hz/Pa to 10 Hz/Pa.

NOTE – Combinations of molar concentration of water vapor and air temperature that imply a relative humidity greater than 100% in 6 1, 6.2, 6.3, and 6.4 are excluded from the corresponding accuracy estimates.

Table 1 – Pure-tone atmospheric-absorption attenuation coefficients at an air pressure of one standard atmosphere (101.325 kPa).

(a) air temperature: -25 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.528	0.519	0.479	0.376	0.290	0.230	0.189	0.160	0.140	0.125	0.114
63	0.633	0.663	0.645	0.540	0.428	0.341	0.278	0.234	0.201	0.178	0.160
80	0.725	0.806	0.831	0.755	0.623	0.504	0.413	0.345	0.295	0.257	0.229
100	0.798	0.934	1.02	1.02	0.889	0.741	0.614	0.514	0.438	0.379	0.334
125	0.854	1.04	1.19	1.31	1.23	1.07	0.906	0.767	0.655	0.566	0.496
160	0.894	1.12	1.33	1.60	1.63	1.50	1.32	1.14	0.979	0.849	0.744
200	0.922	1.18	1.44	1.86	2.05	2.02	1.86	1.65	1.45	1.27	1.12
250	0.943	1.22	1.52	2.08	2.46	2.59	2.52	2.33	2.10	1.88	1.67
315	0.960	1.25	1.58	2.25	2.82	3.16	3.26	3.16	2.96	2.71	2.46
400	0.976	1.28	1.62	2.37	3.10	3.67	4.01	4.10	4.00	3.80	3.53
500	0.994	1.30	1.66	2.47	3.32	4.10	4.69	5.05	5.16	5.09	4.89
630	1.02	1.33	1.69	2.54	3.49	4.44	5.27	5.92	6.32	6.49	6.47
800	1.05	1.37	1.74	2.61	3.62	4.70	5.74	6.65	7.38	7.87	8.14
1000	1.11	1.43	1.80	2.69	3.74	4.90	6.10	7.25	8.27	9.12	9.74
1250	1.20	1.52	1.89	2.79	3.87	5.09	6.40	7.72	9.00	10.2	11.2
1600	1.33	1.65	2.03	2.94	4.04	5.30	6.68	8.13	9.59	11.0	12.3
2000	1.55	1.87	2.25	3.16	4.27	5.56	6.98	8.52	10.1	11.7	13.3
2500	1.89	2.21	2.59	3.50	4.62	5.93	7.39	8.98	10.7	12.4	14.2
3150	2.44	2.76	3.13	4.05	5.17	6.49	7.97	9.60	11.4	13.2	15.1
4000	3.30	3.62	3.99	4.91	6.04	7.36	8.85	10.5	12.3	14.2	16.2
5000	4.66	4.98	5.36	6.28	7.40	8.73	10.2	11.9	13.7	15.7	17.7
6300	6.82	7.14	7.52	8.44	9.57	10.9	12.4	14.1	15.9	17.9	20.0
8000	10.2	10.6	10.9	11.9	13.0	14.3	15.8	17.5	19.4	21.4	23.5
10000	15.7	16.0	16.4	17.3	18.4	19.7	21.3	23.0	24.8	26.8	29.0

(b) air temperature: -20 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.589	0.509	0.418	0.285	0.211	0.168	0.142	0.125	0.114	0.105	0.0991
63	0.756	0.704	0.602	0.421	0.308	0.241	0.200	0.173	0.155	0.142	0.133
80	0.924	0.935	0.846	0.619	0.455	0.352	0.286	0.243	0.214	0.194	0.179
100	1.08	1.18	1.15	0.902	0.675	0.521	0.419	0.350	0.303	0.269	0.245
125	1.20	1.43	1.49	1.28	0.998	0.776	0.621	0.514	0.439	0.384	0.344
160	1.30	1.64	1.83	1.77	1.45	1.16	0.930	0.766	0.648	0.561	0.495
200	1.37	1.82	2.16	2.33	2.06	1.70	1.39	1.15	0.970	0.834	0.730
250	1.43	1.95	2.42	2.93	2.83	2.46	2.06	1.73	1.46	1.26	1.09
315	1.46	2.05	2.64	3.49	3.70	3.43	3.00	2.57	2.20	1.90	1.65
400	1.49	2.12	2.79	3.99	4.60	4.59	4.23	3.74	3.27	2.85	2.50
500	1.52	2.17	2.91	4.38	5.45	5.86	5.72	5.29	4.75	4.23	3.75
630	1.55	2.22	3.00	4.69	6.17	7.10	7.39	7.19	6.71	6.13	5.55
800	1.59	2.28	3.08	4.92	6.76	8.22	9.07	9.31	9.09	8.60	7.98
1000	1.65	2.34	3.17	5.11	7.21	9.14	10.6	11.5	11.7	11.6	11.1
1250	1.74	2.44	3.27	5.28	7.57	9.88	11.9	13.5	14.4	14.8	14.7
1600	1.88	2.58	3.42	5.48	7.90	10.5	13.0	15.2	16.9	18.0	18.6
2000	2.10	2.80	3.65	5.73	8.24	11.0	13.9	16.6	19.0	21.0	22.4
2500	2.44	3.15	4.00	6.10	8.67	11.6	14.7	17.8	20.8	23.5	25.8
3150	2.99	3.70	4.55	6.66	9.27	12.3	15.5	19.0	22.4	25.7	28.8
4000	3.86	4.56	5.42	7.54	10.2	13.2	16.6	20.2	24.0	27.8	31.5
5000	5.24	5.94	6.80	8.93	11.6	14.6	18.1	21.9	25.9	30.0	34.1
6300	7.42	8.12	8.98	11.1	13.8	16.9	20.4	24.2	28.4	32.7	37.1
8000	10.9	11.6	12.4	14.6	17.2	20.3	23.9	27.8	32.0	36.5	41.2
10000	16.4	17.1	17.9	20.1	22.7	25.8	29.4	33.3	37.6	42.2	47.0

[a] See 5.4.3, Note 1.

Table 1 – Continued.

(c) air temperature: -15 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.573	0.425	0.321	0.212	0.164	0.139	0.124	0.114	0.107	0.102	0.0968
63	0.793	0.618	0.472	0.305	0.228	0.188	0.166	0.152	0.142	0.135	0.130
80	1.06	0.885	0.693	0.446	0.324	0.260	0.224	0.202	0.187	0.177	0.170
100	1.34	1.23	1.01	0.660	0.471	0.368	0.308	0.271	0.248	0.232	0.221
125	1.62	1.65	1.44	0.979	0.695	0.532	0.435	0.374	0.334	0.308	0.289
160	1.88	2.11	1.99	1.45	1.04	0.786	0.631	0.531	0.464	0.418	0.386
200	2.08	2.57	2.63	2.10	1.55	1.17	0.932	0.773	0.663	0.587	0.532
250	2.24	2.99	3.32	2.97	2.30	1.76	1.40	1.15	0.973	0.847	0.756
315	2.35	3.33	3.98	4.05	3.34	2.64	2.11	1.73	1.45	1.25	1.10
400	2.43	3.59	4.56	5.27	4.73	3.89	3.17	2.61	2.19	1.88	1.65
500	2.50	3.78	5.03	6.52	6.43	5.61	4.70	3.93	3.32	2.85	2.49
630	2.55	3.93	5.39	7.67	8.35	7.81	6.83	5.85	5.01	4.33	3.78
800	2.61	4.05	5.66	8.65	10.3	10.4	9.62	8.53	7.46	6.53	5.74
1000	2.67	4.15	5.87	9.44	12.1	13.2	13.0	12.1	10.9	9.69	8.64
1250	2.77	4.28	6.07	10.1	13.7	16.0	16.7	16.3	15.3	14.0	12.8
1600	2.91	4.44	6.28	10.6	14.9	18.4	20.5	21.1	20.7	19.7	18.3
2000	3.14	4.67	6.54	11.0	15.9	20.5	23.9	26.0	26.7	26.4	25.4
2500	3.49	5.03	6.92	11.5	16.8	22.2	26.9	30.5	32.7	33.7	33.7
3150	4.04	5.59	7.49	12.2	17.8	23.7	29.4	34.5	38.4	41.0	42.5
4000	4.92	6.47	8.38	13.1	18.9	25.2	31.7	37.9	43.4	47.8	51.1
5000	6.31	7.86	9.78	14.6	20.4	27.1	34.1	41.2	47.9	54.0	59.1
6300	8.52	10.1	12.0	16.8	22.7	29.6	37.0	44.7	52.4	59.8	66.5
8000	12.0	13.6	15.5	20.3	26.3	33.2	40.9	49.0	57.4	65.8	73.9
10000	17.5	19.1	21.0	25.9	31.9	38.9	46.7	55.1	64.0	73.0	82.1

(d) air temperature: -10 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.482	0.325	0.245	0.175	0.146	0.131	0.121	0.113	0.106	0.100	0.0946
63	0.700	0.475	0.350	0.239	0.195	0.174	0.161	0.152	0.145	0.138	0.132
80	1.00	0.697	0.509	0.332	0.261	0.228	0.210	0.199	0.191	0.184	0.179
100	1.39	1.02	0.750	0.472	0.357	0.302	0.273	0.257	0.246	0.239	0.233
125	1.86	1.48	1.11	0.688	0.501	0.409	0.360	0.332	0.315	0.304	0.297
160	2.38	2.10	1.63	1.02	0.721	0.569	0.485	0.436	0.407	0.388	0.376
200	2.89	2.87	2.37	1.52	1.06	0.816	0.676	0.591	0.537	0.503	0.480
250	3.36	3.75	3.35	2.27	1.58	1.20	0.969	0.827	0.734	0.672	0.629
315	3.74	4.66	4.56	3.35	2.38	1.79	1.43	1.19	1.04	0.929	0.853
400	4.03	5.51	5.93	4.86	3.57	2.70	2.13	1.76	1.51	1.33	1.20
500	4.24	6.24	7.32	6.82	5.30	4.07	3.23	2.65	2.24	1.95	1.73
630	4.40	6.81	8.61	9.20	7.70	6.10	4.89	4.01	3.38	2.92	2.57
800	4.53	7.26	9.71	11.8	10.8	8.99	7.36	6.09	5.14	4.43	3.88
1000	4.65	7.59	10.6	14.4	14.6	12.9	10.9	9.19	7.82	6.75	5.91
1250	4.78	7.87	11.3	16.8	18.8	17.9	15.8	13.7	11.8	10.3	9.03
1600	4.94	8.14	11.8	18.8	23.0	23.6	22.1	19.8	17.5	15.5	13.7
2000	5.18	8.44	12.3	20.5	26.8	29.7	29.6	27.8	25.4	22.9	20.6
2500	5.54	8.85	12.8	21.8	30.1	35.6	37.8	37.4	35.5	32.9	30.2
3150	6.11	9.44	13.5	23.1	32.9	40.9	45.9	47.9	47.5	45.7	43.1
4000	7.00	10.3	14.5	24.4	35.4	45.5	53.5	58.5	60.7	60.6	59.0
5000	8.40	11.8	15.9	26.1	37.8	49.6	60.2	68.4	73.9	76.7	77.4
6300	10.6	14.0	18.2	28.6	40.8	53.8	66.4	77.5	86.4	92.8	96.7
8000	14.2	17.5	21.7	32.2	44.8	58.6	72.7	86.2	98.2	108	116
10000	19.7	23.1	27.3	37.9	50.7	65.0	80.2	95.4	110	123	135

[a] See 5.4.3, Note 1.

Table 1 – Continued.

(e) air temperature: -5 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.377	0.257	0.205	0.164	0.145	0.131	0.120	0.111	0.102	0.0945	0.0878
63	0.547	0.361	0.279	0.216	0.192	0.177	0.166	0.155	0.146	0.137	0.129
80	0.801	0.518	0.387	0.285	0.249	0.232	0.220	0.210	0.201	0.192	0.183
100	1.17	0.756	0.549	0.381	0.323	0.298	0.284	0.275	0.267	0.259	0.251
125	1.69	1.12	0.796	0.522	0.423	0.381	0.361	0.350	0.343	0.337	0.330
160	2.38	1.65	1.17	0.736	0.568	0.493	0.458	0.440	0.431	0.425	0.421
200	3.23	2.42	1.75	1.07	0.787	0.656	0.591	0.557	0.539	0.530	0.525
250	4.20	3.49	2.60	1.58	1.12	0.903	0.785	0.720	0.683	0.662	0.651
315	5.19	4.87	3.83	2.36	1.65	1.28	1.08	0.961	0.889	0.845	0.818
400	6.10	6.53	5.53	3.55	2.46	1.88	1.54	1.33	1.20	1.11	1.06
500	6.87	8.34	7.72	5.31	3.71	2.80	2.25	1.91	1.68	1.52	1.42
630	7.48	10.1	10.3	7.83	5.61	4.22	3.36	2.80	2.43	2.16	1.97
800	7.94	11.7	13.2	11.3	8.42	6.41	5.09	4.21	3.60	3.16	2.84
1000	8.29	13.1	16.0	15.7	12.4	9.69	7.74	6.38	5.42	4.72	4.20
1250	8.58	14.1	18.5	20.8	17.9	14.5	11.7	9.73	8.26	7.16	6.33
1600	8.85	14.9	20.6	26.4	24.9	21.2	17.6	14.8	12.6	10.9	9.65
2000	9.16	15.6	22.3	31.8	33.2	30.1	26.0	22.2	19.2	16.7	14.8
2500	9.57	16.3	23.8	36.6	42.1	41.1	37.2	32.8	28.8	25.4	22.5
3150	10.2	17.0	25.0	40.7	50.8	53.5	51.3	47.0	42.3	38.0	34.1
4000	11.1	18.1	26.4	44.2	58.7	66.4	67.7	65.0	60.5	55.5	50.7
5000	12.5	19.6	28.1	47.5	65.7	78.7	85.1	86.0	83.3	78.8	73.6
6300	14.8	21.9	30.6	51.0	72.1	89.9	102	108	110	107	103
8000	18.3	25.5	34.3	55.4	78.5	100	118	131	138	140	139
10000	24.0	31.1	40.0	61.6	86.2	111	134	152	166	174	179

(f) air temperature: 0 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.302	0.226	0.195	0.165	0.144	0.128	0.114	0.1025	0.0928	0.0846	0.0777
63	0.424	0.302	0.256	0.219	0.198	0.181	0.165	0.151	0.138	0.127	0.118
80	0.607	0.411	0.337	0.284	0.263	0.246	0.230	0.215	0.201	0.187	0.175
100	0.884	0.573	0.449	0.364	0.338	0.323	0.309	0.296	0.281	0.267	0.253
125	1.30	0.818	0.614	0.469	0.427	0.411	0.401	0.390	0.379	0.367	0.354
160	1.92	1.19	0.865	0.617	0.541	0.514	0.504	0.498	0.491	0.483	0.474
200	2.80	1.77	1.25	0.835	0.696	0.644	0.626	0.619	0.616	0.614	0.610
250	4.00	2.63	1.85	1.17	0.922	0.822	0.779	0.763	0.759	0.760	0.761
315	5.53	3.91	2.76	1.69	1.27	1.08	0.992	0.951	0.934	0.930	0.932
400	7.33	5.71	4.14	2.49	1.80	1.47	1.30	1.21	1.17	1.15	1.14
500	9.25	8.14	6.16	3.73	2.63	2.08	1.78	1.61	1.51	1.45	1.42
630	11.1	11.2	9.03	5.64	3.93	3.03	2.52	2.21	2.02	1.90	1.82
800	12.7	14.7	12.9	8.50	5.93	4.52	3.68	3.16	2.82	2.59	2.43
1000	14.0	18.3	17.7	12.7	9.00	6.83	5.50	4.64	4.06	3.66	3.37
1250	15.1	21.8	23.3	18.6	13.6	10.4	8.33	6.96	6.01	5.34	4.85
1600	15.9	24.8	29.1	26.4	20.3	15.8	12.7	10.6	9.07	7.98	7.16
2000	16.5	27.2	34.6	36.0	29.8	23.8	19.3	16.1	13.8	12.1	10.8
2500	17.2	29.2	39.5	47.0	42.3	35.3	29.2	24.6	21.2	18.5	16.5
3150	18.0	30.9	43.6	58.2	57.8	50.9	43.5	37.3	32.3	28.4	25.2
4000	19.0	32.6	47.0	69.0	75.2	71.0	63.3	55.5	48.8	43.2	38.7
5000	20.5	34.5	50.2	78.5	93.4	94.8	89.0	80.7	72.5	65.1	58.8
6300	22.8	37.1	53.7	87.1	111	121	120	113	105	96.2	88.0
8000	26.4	40.9	58.1	95.2	127	147	154	153	147	138	129
10000	32.2	46.7	64.3	104	142	172	190	198	197	191	183

[a] See 5.4.3, Note 1.

Table 1 – Continued.

(g) air temperature: +5 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0 268	0 220	0.197	0 164	0.138	0 118	0.103	0 0910	0 0812	0 0733	0.0667
63	0.359	0 289	0 261	0 227	0.199	0.175	0.155	0.138	0.124	0.113	0.103
80	0.488	0 375	0 337	0 303	0 276	0.250	0.227	0.206	0.188	0.172	0.158
100	0 680	0 492	0.431	0 391	0.369	0 345	0.321	0.298	0 276	0 256	0 238
125	0 971	0.661	0.554	0 493	0.474	0 458	0.438	0 416	0.393	0 371	0.349
160	1.42	0 914	0 729	0 617	0 594	0.585	0 574	0.558	0 539	0 518	0.496
200	2.10	1.30	0.988	0.781	0.735	0.727	0.725	0.720	0.710	0 696	0.678
250	3.11	1 90	1 38	1 01	0 915	0 892	0 892	0 897	0 899	0 896	0 888
315	4 58	2 82	2 00	1 36	1.16	1 10	1.09	1.09	1 10	1 11	1.12
400	6.64	4 23	2 95	1.90	1.53	1.39	1.34	1 33	1 34	1 35	1 37
500	9 34	6 32	4.42	2.74	2 10	1 82	1.69	1.64	1.63	1.64	1 66
630	12.6	9.34	6 66	4.04	2 97	2.47	2 22	2 09	2.03	2.01	2.01
800	16 3	13 5	10.0	6 07	4 34	3 49	3.03	2.76	2 61	2 53	2.49
1000	20 0	18.9	14 8	9 18	6.49	5 08	4 29	3.80	3.50	3.31	3 20
1250	23.4	25.4	21.5	13.9	9.81	7 58	6.26	5 43	4 89	4 52	4.27
1600	26 2	32.6	30 1	20 9	14.9	11 5	9.35	7.99	7 06	6.42	5.95
2000	28 5	39 6	40.5	30 9	22 7	17 5	14 2	12 0	10.5	9 39	8.59
2500	30.4	46.1	51 9	44 6	34.1	26 6	21.7	18 2	15 8	14 1	12.7
3150	31 9	51.6	63.2	62 0	50 4	40.3	33 1	27 9	24 2	21.4	19.2
4000	33 5	56.2	73.7	82.6	72.5	60.2	50.2	42.7	37 0	32 7	29.4
5000	35 4	60.2	82.8	105	101	87.8	75 2	64.8	56.6	50.2	45.1
6300	38 0	64 3	90 9	127	133	124	110	97 0	85 8	76.6	69.1
8000	41.8	69.1	98.6	147	169	168	156	142	128	116	105
10000	47.7	75.6	107	167	205	218	214	201	186	172	158

(h) air temperature: +10 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.262	0.224	0 197	0.155	0.126	0.105	0.0901	0 0785	0 0696	0.0624	0.0565
63	0.342	0.298	0 271	0 225	0 188	0.160	0.139	0.122	0.108	0.0975	0 0885
80	0.445	0 385	0.359	0 316	0 274	0.239	0.210	0.186	0.167	0.151	0.138
100	0.585	0.490	0.461	0.425	0.386	0.347	0.311	0.280	0.254	0.231	0.212
125	0.788	0.623	0.579	0 551	0.522	0.486	0.447	0.411	0.378	0.348	0.322
160	1.09	0.806	0 725	0.692	0.678	0.653	0 620	0 584	0 547	0.512	0.479
200	1.56	1.07	0.919	0 852	0.849	0.843	0.825	0.797	0.764	0.728	0.692
250	2 29	1.48	1 20	1.05	1.04	1 05	1 05	1 04	1.02	1.00	0.963
315	3 39	2.11	1.62	1.31	1.27	1.28	1.30	1 31	1.31	1.30	1 29
400	5.06	3.08	2.26	1 70	1.56	1 55	1.57	1.60	1.63	1.64	1.65
500	7.52	4.59	3.27	2.28	1.98	1.90	1.90	1.93	1.97	2.00	2 03
630	11.0	6.89	4.84	3 18	2.60	2.39	2.32	2.33	2.36	2.40	2.45
800	15 7	10 4	7 27	4 58	3.56	3.13	2 94	2.87	2.86	2.89	2.93
1000	21.6	15.4	11.0	6.77	5 07	4.26	3 86	3.66	3.57	3.54	3.55
1250	28.4	22 6	16 6	10 2	7.42	6.04	5.29	4.86	4.62	4 48	4 42
1600	35.5	32.1	24.7	15 5	11.1	8.83	7 53	6.73	6 23	5.92	5.72
2000	42.3	43.8	36.2	23.5	16 8	13.2	11.0	9.66	8.76	8.14	7.71
2500	48.3	57 2	51.4	35 4	25.7	20.0	16.5	14 3	12.7	11.6	10 8
3150	53.2	71.0	70 2	52.7	39.1	30.6	25.1	21.5	19.0	17.1	15.7
4000	57.3	84.0	91 5	76.6	59.0	46.7	38.4	32.8	28.7	25.7	23 5
5000	61.0	95.6	113	108	87.5	70 8	58.8	50.2	43.9	39.2	35 6
6300	64.8	106	135	145	127	106	89.4	76.9	67.4	60.2	54 4
8000	69.4	115	154	187	177	155	134	117	103	92.4	83 7
10000	75.8	125	172	230	237	220	197	175	157	141	128

[a] See 5.4.3, Note 1.

Table 1 – Continued.

(i) air temperature: +15 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km) Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.268	0.224	0.189	0.141	0.111	0.0914	0.0774	0.0670	0.0591	0.0528	0.0477
63	0.353	0.310	0.272	0.212	0.171	0.142	0.121	0.105	0.0927	0.0830	0.0752
80	0.454	0.413	0.378	0.311	0.257	0.217	0.187	0.163	0.145	0.130	0.118
100	0.577	0.531	0.504	0.441	0.378	0.326	0.285	0.251	0.224	0.202	0.184
125	0.735	0.667	0.647	0.601	0.539	0.479	0.426	0.381	0.343	0.312	0.285
160	0.956	0.828	0.806	0.786	0.740	0.681	0.621	0.565	0.516	0.473	0.436
200	1.28	1.04	0.991	0.989	0.973	0.930	0.874	0.815	0.757	0.704	0.655
250	1.78	1.33	1.22	1.21	1.23	1.22	1.18	1.13	1.07	1.02	0.959
315	2.55	1.77	1.54	1.47	1.50	1.53	1.53	1.51	1.47	1.41	1.36
400	3.74	2.44	2.00	1.79	1.81	1.87	1.91	1.92	1.91	1.89	1.85
500	5.58	3.49	2.70	2.23	2.18	2.24	2.31	2.36	2.40	2.41	2.41
630	8.36	5.11	3.80	2.89	2.68	2.69	2.75	2.84	2.91	2.97	3.01
800	12.5	7.63	5.50	3.89	3.41	3.29	3.31	3.38	3.48	3.57	3.65
1000	18.4	11.5	8.17	5.45	4.51	4.16	4.06	4.08	4.15	4.25	4.35
1250	26.5	17.4	12.3	7.90	6.22	5.49	5.17	5.05	5.05	5.11	5.20
1600	36.9	26.0	18.6	11.7	8.90	7.55	6.86	6.51	6.35	6.30	6.32
2000	49.3	38.3	28.2	17.7	13.1	10.8	9.50	8.75	8.31	8.07	7.95
2500	62.5	54.8	42.2	26.9	19.7	15.9	13.6	12.2	11.4	10.8	10.4
3150	75.5	75.7	62.1	41.0	29.9	23.8	20.1	17.7	16.1	15.0	14.3
4000	87.3	99.9	88.8	62.0	45.7	36.2	30.3	26.4	23.7	21.7	20.3
5000	97.4	126	122	92.4	69.7	55.4	46.2	39.9	35.5	32.2	29.8
6300	106	151	161	135	105	84.7	70.8	61.1	54.0	48.7	44.7
8000	114	174	202	190	156	129	108	93.7	82.8	74.5	68.1
10000	123	195	242	257	226	192	165	144	127	115	105

(j) air temperature: +20 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km) Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.270	0.214	0.174	0.125	0.0965	0.0784	0.0660	0.0570	0.0501	0.0447	0.0403
63	0.370	0.310	0.260	0.192	0.150	0.123	0.104	0.0897	0.0790	0.0705	0.0637
80	0.487	0.432	0.377	0.290	0.231	0.191	0.162	0.141	0.124	0.111	0.100
100	0.622	0.579	0.529	0.429	0.351	0.294	0.252	0.219	0.194	0.174	0.158
125	0.776	0.746	0.712	0.615	0.521	0.445	0.386	0.339	0.302	0.272	0.247
160	0.965	0.931	0.919	0.848	0.752	0.660	0.582	0.518	0.465	0.421	0.384
200	1.22	1.14	1.14	1.12	1.05	0.950	0.858	0.776	0.705	0.644	0.591
250	1.58	1.39	1.39	1.42	1.39	1.32	1.23	1.13	1.04	0.966	0.895
315	2.12	1.74	1.69	1.75	1.78	1.75	1.68	1.60	1.50	1.41	1.32
400	2.95	2.23	2.06	2.10	2.19	2.23	2.21	2.16	2.08	2.00	1.90
500	4.25	2.97	2.60	2.52	2.63	2.73	2.79	2.80	2.77	2.71	2.63
630	6.26	4.12	3.39	3.06	3.13	3.27	3.40	3.48	3.52	3.52	3.49
800	9.36	5.92	4.62	3.84	3.77	3.89	4.05	4.19	4.31	4.39	4.43
1000	14.1	8.72	6.53	5.00	4.65	4.66	4.80	4.98	5.15	5.30	5.42
1250	21.1	13.1	9.53	6.81	5.97	5.75	5.78	5.92	6.10	6.29	6.48
1600	31.3	19.8	14.2	9.63	8.00	7.37	7.17	7.18	7.31	7.48	7.68
2000	45.3	29.9	21.5	14.1	11.2	9.85	9.25	9.02	8.98	9.06	9.21
2500	63.5	44.8	32.6	21.0	16.1	13.7	12.5	11.8	11.5	11.3	11.3
3150	85.4	66.2	49.4	31.8	23.9	19.8	17.5	16.1	15.3	14.8	14.5
4000	109	95.1	74.1	48.5	36.1	29.4	25.4	22.9	21.3	20.2	19.4
5000	133	132	109	73.8	55.1	44.4	37.9	33.6	30.6	28.6	27.1
6300	156	175	156	112	84.2	67.8	57.4	50.3	45.4	41.8	39.1
8000	175	221	215	166	128	104	87.8	76.6	68.6	62.6	58.1
10000	193	267	284	242	194	159	135	117	105	95.3	87.9

[a] See 5.4.3, Note 1.

Table 1 – Continued.

(k) air temperature: +25 °C

Nominal frequency[a)] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.262	0.197	0.156	0.109	0.0830	0.0671	0.0563	0.0484	0.0425	0.0379	0.0342
63	0.374	0.295	0.238	0.169	0.130	0.106	0.0887	0.0765	0.0672	0.0600	0.0541
80	0.515	0.429	0.357	0.261	0.203	0.166	0.140	0.121	0.106	0.0947	0.0856
100	0.681	0.604	0.523	0.397	0.314	0.258	0.219	0.190	0.167	0.149	0.135
125	0.867	0.816	0.740	0.591	0.479	0.399	0.340	0.296	0.262	0.235	0.213
160	1.07	1.06	1.01	0.856	0.717	0.608	0.525	0.460	0.409	0.367	0.333
200	1.31	1.32	1.31	1.20	1.05	0.909	0.797	0.706	0.631	0.570	0.520
250	1.61	1.60	1.64	1.60	1.47	1.32	1.18	1.06	0.963	0.876	0.802
315	2.02	1.93	1.99	2.05	1.99	1.86	1.71	1.57	1.44	1.32	1.22
400	2.63	2.35	2.38	2.53	2.57	2.51	2.38	2.24	2.10	1.96	1.83
500	3.56	2.92	2.86	3.04	3.19	3.23	3.18	3.08	2.95	2.80	2.66
630	5.00	3.78	3.50	3.61	3.84	4.00	4.06	4.05	3.97	3.86	3.73
800	7.24	5.09	4.44	4.31	4.55	4.80	4.99	5.09	5.12	5.09	5.02
1000	10.7	7.13	5.87	5.27	5.39	5.68	5.96	6.19	6.35	6.44	6.47
1250	16.1	10.3	8.09	6.68	6.53	6.73	7.04	7.35	7.62	7.84	8.00
1600	24.3	15.3	11.6	8.85	8.16	8.14	8.36	8.68	9.01	9.33	9.61
2000	36.5	23.0	17.0	12.2	10.7	10.2	10.2	10.4	10.7	11.0	11.4
2500	54.2	34.9	25.5	17.5	14.5	13.3	12.8	12.8	12.9	13.2	13.5
3150	78.6	52.9	38.6	25.8	20.6	18.1	16.9	16.3	16.2	16.2	16.4
4000	110	79.4	58.8	38.8	30.1	25.7	23.2	21.9	21.1	20.8	20.6
5000	149	117	89.1	58.9	45.0	37.6	33.2	30.5	28.8	27.7	27.1
6300	191	168	133	90.0	68.3	56.2	48.8	44.1	40.8	38.6	37.1
8000	233	232	196	137	104	85.4	73.4	65.4	59.8	55.8	52.8
10000	274	308	279	207	160	131	112	98.9	89.6	82.8	77.6

(l) air temperature: +30 °C

Nominal frequency[a)] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.244	0.177	0.137	0.0939	0.0713	0.0574	0.0481	0.0413	0.0363	0.0323	0.0292
63	0.362	0.270	0.212	0.147	0.112	0.0907	0.0760	0.0654	0.0574	0.0512	0.0462
80	0.521	0.406	0.326	0.230	0.176	0.143	0.120	0.103	0.0908	0.0810	0.0731
100	0.721	0.595	0.492	0.356	0.276	0.224	0.189	0.163	0.143	0.128	0.116
125	0.958	0.844	0.725	0.543	0.427	0.350	0.296	0.256	0.226	0.202	0.182
160	1.22	1.15	1.03	0.815	0.655	0.543	0.462	0.402	0.355	0.318	0.287
200	1.51	1.50	1.42	1.19	0.987	0.832	0.715	0.625	0.554	0.498	0.451
250	1.82	1.88	1.87	1.68	1.45	1.25	1.09	0.963	0.859	0.775	0.705
315	2.20	2.28	2.35	2.28	2.07	1.84	1.63	1.46	1.32	1.20	1.09
400	2.69	2.73	2.86	2.95	2.83	2.61	2.38	2.17	1.98	1.82	1.67
500	3.40	3.26	3.41	3.67	3.70	3.57	3.36	3.13	2.91	2.71	2.52
630	4.46	3.96	4.04	4.41	4.63	4.66	4.55	4.36	4.14	3.92	3.70
800	6.10	4.98	4.85	5.21	5.60	5.82	5.88	5.81	5.66	5.47	5.25
1000	8.67	6.52	6.00	6.15	6.63	7.03	7.29	7.41	7.41	7.32	7.17
1250	12.7	8.91	7.72	7.39	7.80	8.31	8.75	9.08	9.28	9.37	9.37
1600	18.9	12.6	10.4	9.17	9.30	9.78	10.3	10.8	11.2	11.5	11.7
2000	28.5	18.5	14.5	11.8	11.4	11.7	12.2	12.7	13.3	13.8	14.2
2500	43.1	27.6	21.0	16.0	14.6	14.3	14.6	15.1	15.7	16.3	16.8
3150	64.8	41.8	31.2	22.5	19.4	18.3	18.1	18.3	18.8	19.3	19.9
4000	96.0	63.5	47.1	32.7	27.0	24.5	23.4	23.1	23.1	23.5	24.0
5000	139	96.1	71.6	48.7	39.0	34.1	31.6	30.3	29.7	29.6	29.7
6300	194	144	109	73.7	57.7	49.3	44.4	41.6	39.8	38.9	38.4
8000	260	211	165	112.5	87.1	73.1	64.7	59.3	55.7	53.3	51.8
10000	332	301	246	172	133	111	96.5	87.1	80.7	76.1	72.8

a) See 5.4.3, Note 1.

Table 1 – Continued.

(m) air temperature: +35 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.222	0.156	0.119	0.0810	0.0613	0.0493	0.0412	0 0354	0 0311	0 0277	0.0250
63	0.337	0 242	0.187	0.128	0.0968	0.0779	0.0652	0.0561	0 0492	0 0439	0.0396
80	0.501	0.371	0.290	0.201	0 153	0.123	0.103	0.0888	0.0779	0.0695	0 0627
100	0.725	0.560	0.447	0.314	0.240	0.194	0.163	0.140	0.123	0.110	0 0992
125	1.01	0.826	0.677	0.486	0.376	0.305	0.257	0.221	0.195	0.174	0.157
160	1.35	1.18	1.00	0.746	0.584	0.478	0.403	0.349	0.307	0.274	0.248
200	1.73	1.62	1.45	1.12	0.898	0.742	0.630	0.547	0.483	0.432	0.391
250	2.13	2.13	2.00	1.65	1.36	1.14	0 977	0.853	0.756	0.678	0.614
315	2.56	2 69	2.66	2.36	2.01	1.73	1.50	1.32	1.17	1.06	0.961
400	3.05	3.27	3.37	3 23	2.89	2 55	2 26	2.01	1.81	1.64	1.49
500	3.66	3.88	4.12	4 22	4.00	3.66	3 32	3.01	2.73	2.50	2.30
630	4.52	4.59	4.90	5.30	5.29	5.05	4.72	4.38	4.05	3.74	3.47
800	5.78	5.48	5.76	6.40	6 69	6.67	6.46	6 15	5 81	5.47	5.14
1000	7.71	6.74	6.82	7.55	8.15	8.43	8.45	8.30	8.03	7.71	7.37
1250	10.7	8.61	8.28	8.86	9 65	10.3	10.6	10 7	10 6	10.4	10.2
1600	15.4	11.5	10 4	10.5	11 3	12.1	12 8	13 2	13.5	13.5	13.5
2000	22 8	16.0	13.7	12.8	13.4	14.2	15 1	15.9	16.4	16.8	17.1
2500	34.2	23.1	18 8	16.2	16.1	16.8	17.8	18.7	19.5	20.2	20.8
3150	51.8	34.1	26.8	21.5	20.2	20.4	21 1	22.0	23.0	24.0	24.8
4000	78.3	51.3	39.3	29.7	26.5	25.7	25.8	26 5	27.4	28.3	29.3
5000	118	78.0	58.9	42.6	36.3	33.8	32.9	32.9	33.4	34.2	35.1
6300	173	119	89.4	62 8	51.7	46.4	43.7	42.6	42.3	42.5	43.1
8000	249	179	136	94.5	75.8	66.1	60.7	57.6	56.0	55.2	55.0
10000	345	267	207	144	114	97.3	87.4	81.3	77.3	74.9	73.4

(n) air temperature: +40 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km)										
	Relative humidity (%)										
	10	15	20	30	40	50	60	70	80	90	100
50	0.198	0.136	0.104	0 0700	0.0529	0.0425	0.0355	0.0305	0.0268	0.0239	0.0215
63	0.306	0.214	0.163	0.111	0.0836	0.0672	0.0562	0.0483	0.0424	0.0378	0.0341
80	0.465	0.332	0.256	0.174	0.132	0.106	0.0890	0.0765	0.0672	0.0599	0.0540
100	0.695	0.511	0.398	0.274	0.208	0.168	0.141	0.121	0.106	0.0948	0.0856
125	1.01	0.774	0.615	0.429	0.328	0.265	0 222	0.192	0.168	0.150	0.135
160	1.42	1.15	0 935	0.667	0.514	0.417	0.351	0.302	0.266	0.237	0.214
200	1.91	1 65	1.39	1.03	0.800	0.653	0.551	0.476	0.419	0.375	0.339
250	2.45	2.28	2.02	1.55	1.23	1.02	0.863	0.748	0.660	0.590	0.534
315	3 03	3.03	2.82	2 30	1.88	1.57	1.34	1.17	1.03	0.927	0.840
400	3.63	3.84	3.77	3.30	2.79	2.38	2.06	1.81	1.61	1.45	1.32
500	4 28	4.68	4.82	4.56	4.04	3.54	3.12	2.77	2.48	2.25	2.05
630	5.08	5.55	5.92	6.02	5.64	5.12	4.61	4.16	3.77	3.44	3.16
800	6.14	6.51	7.04	7.61	7.53	7.13	6.62	6.10	5.62	5.19	4.80
1000	7.68	7.68	8.25	9.24	9.62	9.52	9.14	8 66	8.14	7.62	7.14
1250	10.0	9.28	9.68	10.9	11.8	12.1	12.1	11.8	11.4	10.9	10 3
1600	13.6	11.6	11.6	12.8	14.0	14.9	15.3	15.4	15.2	14.8	14.4
2000	19.3	15.2	14.3	15.0	16.4	17.7	18.6	19.2	19.4	19.4	19.3
2500	28.2	20.8	18.4	18.0	19.2	20.7	22.0	23.1	23.9	24.4	24.6
3150	42.1	29.5	24 9	22.5	23.0	24.4	25.9	27.3	28.5	29.6	30.3
4000	63 6	43.2	35.0	29.3	28 5	29.2	30.6	32.1	33.7	35.1	36.3
5000	96.4	64.6	50.8	39 9	36.8	36.3	37.1	38.4	39.9	41.5	43.0
6300	146	97.9	75.6	56 6	49.7	47.2	46.7	47.2	48.3	49.7	51.3
8000	217	149	114	82 8	69.9	64.0	61.4	60 5	60.7	61 5	62.7
10000	318	226	174	124	102	90.4	84.3	81.0	79.5	79.1	79.4

[a] See 5 4 3, Note 1.

Table 1 – Concluded.

(o) air temperature: +45 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km) Relative humidity (%) 10	15	20	30	40	50	60	70	80	90	100
50	0 175	0.119	0.0902	0.0607	0.0458	0.0368	0.0307	0.0264	0.0232	0.0207	0.0186
63	0.273	0 187	0.142	0.0960	0.0725	0.0582	0 0487	0.0419	0.0367	0.0327	0 0295
80	0.422	0.294	0 224	0.152	0.115	0.0922	0.0771	0.0663	0 0582	0.0519	0 0468
100	0.644	0.457	0.352	0.239	0.181	0.146	0.122	0.105	0 0921	0.0821	0.0741
125	0.965	0 705	0.548	0.377	0.286	0.230	0 193	0.166	0.146	0.130	0.117
160	1.41	1 07	0.848	0 590	0.450	0 364	0.305	0.263	0.231	0 206	0.186
200	1.98	1 59	1.29	0.918	0.706	0.573	0.481	0.415	0.365	0.326	0.294
250	2.68	2.30	1.93	1 41	1.10	0.898	0.757	0.654	0 576	0 514	0.465
315	3.47	3.21	2.82	2.15	1.70	1.40	1.19	1.03	0.907	0.811	0.734
400	4.30	4 28	3.96	3.19	2 59	2.16	1.85	1.61	1.42	1 27	1.15
500	5.15	5.46	5.34	4.61	3.88	3 29	2.84	2.49	2.22	1.99	1.81
630	6.05	6 68	6 87	6.42	5 65	4 92	4.32	3 83	3 43	3.10	2.82
800	7 09	7.92	8.47	8 55	7 93	7.16	6.42	5 78	5 23	4.76	4.36
1000	8.45	9.25	10.1	10.9	10.7	10.0	9.27	8.51	7 82	7.20	6.65
1250	10.4	10.8	11.8	13.3	13.8	13.5	12.9	12 2	11.4	10 6	9.94
1600	13.3	12 9	13.8	15.7	17.0	17.4	17 2	16.7	16 0	15 2	14.5
2000	17.8	15.9	16 3	18.4	20.2	21.4	21.9	21.9	21.6	21 0	20.3
2500	24 8	20 5	19.9	21.5	23.7	25 6	26.9	27.6	27.9	27.8	27.4
3150	35.8	27 5	25 2	25.6	27.7	30 0	32.0	33 5	34.5	35.1	35.4
4000	53 0	38.6	33.5	31.5	32.9	35 2	37.5	39.7	41.5	42 9	43 9
5000	79.8	56.0	46 5	40.6	40.3	42 0	44.3	46.7	49.0	51.1	52 9
6300	121	83.2	66.9	54.6	51.5	51.7	53.3	55.6	58.0	60.4	62.8
8000	184	126	98.9	76.6	68 8	66 5	66.6	68.0	70.0	72.4	74 8
10000	276	191	149	111	96.0	89.4	86.8	86.5	87.4	89.1	91.2

(p) air temperature: +50 °C

Nominal frequency[a] (Hz)	Attenuation coefficient (dB/km) Relative humidity (%) 10	15	20	30	40	50	60	70	80	90	100
50	0.154	0.104	0.0787	0.0528	0.0398	0.0320	0.0267	0.0230	0.0202	0.0180	0.0162
63	0.242	0.164	0.124	0.0836	0.0630	0.0506	0.0423	0.0364	0.0320	0.0285	0.0257
80	0.377	0.259	0.196	0.132	0.100	0.0802	0.0671	0.0577	0.0506	0.0451	0.0407
100	0.584	0.406	0.309	0.209	0.158	0.127	0.106	0.0914	0 0802	0 0715	0 0645
125	0.893	0.632	0.485	0.330	0.250	0.201	0.168	0.145	0 127	0.113	0.102
160	1.34	0.976	0.758	0.519	0.394	0 318	0 266	0.229	0.201	0.179	0.162
200	1.96	1.49	1.17	0.814	0.621	0.501	0.421	0.362	0.318	0.284	0.256
250	2.78	2.22	1.79	1.27	0.974	0.790	0.664	0.572	0.503	0.449	0.406
315	3.78	3.22	2.69	1.96	1.52	1.24	1.04	0.902	0.794	0.710	0.642
400	4.90	4 51	3.93	2.98	2.35	1.93	1.64	1.42	1.25	1.12	1.01
500	6.09	6.05	5.55	4.45	3.60	2.99	2.55	2.22	1 96	1 76	1.60
630	7.30	7.75	7.53	6.45	5 40	4.57	3.94	3.45	3.07	2.76	2 50
800	8.55	9.51	9.75	9.02	7.89	6.85	6.00	5.31	4.75	4.29	3 91
1000	9.95	11.3	12.1	12.1	11.1	10 0	8 95	8.03	7.25	6.60	6.05
1250	11.7	13 2	14.4	15.5	15 1	14 1	13 0	11.9	10.9	10 0	9.24
1600	14.2	15.3	16.9	19.0	19.6	19.1	18.2	17.1	15.9	14.9	13.9
2000	17.9	18.1	19.6	22.6	24.3	24.8	24.4	23.6	22.5	21.4	20 3
2500	23.6	22.0	23.0	26.3	29.1	30 7	31.3	31 2	30.6	29.7	28.7
3150	32.5	27 9	27.8	30.7	34.1	36.8	38.6	39.5	39.8	39.6	38.9
4000	46.4	37.1	34.9	36 3	39.8	43.2	46.1	48.2	49 6	50.4	50 6
5000	68.2	51.4	45.8	44.4	47.0	50.6	54.2	57.3	59.9	61.8	63.2
6300	102	73.9	62.9	56.6	57.3	60.2	63.9	67 5	71.0	74.0	76 5
8000	155	109	89.7	75.4	72.6	73.8	76.7	80.3	84.1	87.7	91.2
10000	235	164	132	105	96.3	94.3	95.4	98.0	101	105	109

[a] See 5.4.3, Note 1.

7 Calculation of attenuation by atmospheric absorption for wideband sounds analyzed by fractional-octave-band filters

7.1 Description of the general problem and calculation methods

7.1.1 Previous clauses of this Standard have considered the effects of atmospheric absorption on the reduction of the level of pure-tone sounds during propagation through the atmosphere. In practice, however, the spectrum of most sounds covers a wide range of frequencies, and spectral analysis is often performed by fractional-octave-band filters that yield sound pressure levels in frequency bands.

7.1.2 When a wideband sound-pressure signal is analyzed by fractional-octave-band filters, the measured band sound pressure levels include the influence of the attenuation response characteristics of practical filters as well as the attenuation introduced by atmospheric absorption.

The magnitude of these effects varies with the slope of the spectrum of the signal applied to the filter and the filter's attenuation-response characteristic.

High-frequency sound pressure levels measured at the location of a distant receiver are particularly vulnerable to these effects because the attenuation by atmospheric absorption normally increases rapidly with increasing frequency, thereby causing large negative spectral slopes for the sound-pressure signal incident on a microphone. Thus, there is the potential for significant contributions at frequencies less than the lower band-edge frequency of a filter's passband.

7.1.3 A simple procedure is needed to deal with the unavoidable influence of atmospheric-absorption effects inherent in spectral analyses of sounds by fractional-octave-band filters. To meet this need, this Standard provides (in 7.2) a calculation method based solely on a discrete-frequency approximation of the attenuation actually experienced by a broadband sound. The approximate discrete-frequency (pure-tone) calculation method is applicable to many practical situations.

The approximate method provides values for attenuation by atmospheric absorption that are within ±5% of the attenuations calculated by the method of annex D when the attenuation by atmospheric absorption over the sound-propagation path is less than approximately 20 dB for any one-third-octave band of interest.

As a conservative estimate, the limitation on an attenuation of 20 dB will generally be applicable, for one-third-octave-band filters, when the product of the source-receiver pathlength, in kilometres, and the square of the nominal midband frequency, in kilohertz, is less than 2 km • (kHz)^2 and the pathlength does not exceed 1 km at any midband frequency.

7.1.4 A general description is also provided (in 7.3) for application of the pure-tone calculation method when the spectrum of the sound is a combination of significant discrete-frequency components superposed on a wideband spectrum.

7.1.5 Annex D describes an alternative spectrum-integration method to calculate the attenuation caused by atmospheric absorption for a wideband sound analyzed by fractional-octave-band filters. The method in annex D requires knowledge of the sound-pressure signal at the microphone as a continuous function of frequency to evaluate an integral by numerical techniques. The numerical-integration method yields more-accurate estimates for band-level attenuations caused by atmospheric absorption and is applicable over a wider range of conditions than the approximate pure-tone method described in 7.2.

Annex E describes an empirical method to approximate the numerical-integration procedure of annex D in a practical manner for fractional-octave-band filters. The method of annex E provides values for attenuation by atmospheric absorption that are within ±5% of the attenuations calculated by the method of annex D when the attenuation by atmospheric absorption over the sound-propagation path is less than approximately 50 dB for any one-third-octave band of interest.

7.1.6 The methods in 7.2, 7.3, and annexes D and E are applicable to the calculation of band-level attenuation of the sound produced by stationary or moving sound sources. If the sound source moves during the period of interest, the attenuation from atmospheric absorption will vary with time because the effective frequency (or effective wavelength) varies with time owing to the Doppler effect. The Doppler effect should be taken into account by calculating the attenuation coefficient for the Doppler-shifted frequency applicable to the sound-emission angle for each time of interest.

7.2 Pure-tone method to approximate band-level attenuation

For each fractional-octave band of interest and for specified meteorological conditions along the sound-propagation path, calculate the attenuation coefficient by the procedure described in clause 5 for the exact midband frequency [Eq. (6)]. The band-level attenuation for each frequency band, in decibels, is then the product of the attenuation coefficient for the exact midband frequency and the pathlength, as in Eq. (2) for pure tones.

7.3 Combined wideband and pure-tone sounds

For sound signals consisting of a wideband component plus one or more significant pure-tone components, where practical, the following procedure should be used to calculate the attenuation of fractional-octave-band sound pressure levels as a result of atmospheric absorption.

Step 1 Separate the measured spectrum, on the basis of time-mean-square sound pressures, into pure-tone and wideband components. For pure-tone components, the frequency of the tone may be determined by spectrum analysis with a narrow-band filter, by prior knowledge of the source of the tones, or, (if no better estimate is available) by a defined protocol for estimating the presence and level of a pure tone based solely on relative changes in the level of adjacent fractional-octave-band sound pressure levels. For the latter case, (if no better estimate is available) the frequency of the tone may be assumed to be the exact midband frequency of the filter band.

NOTE – If the approximate method of 7.2 is used for the wideband element, and if the frequency of the tone is also assumed to be the exact midband frequency of the filter band, then the procedure of separating the spectral components is not necessary because the same pure-tone attenuation would apply to both the wideband and discrete-frequency components.

Step 2 Calculate the attenuation over the specified pathlength for each spectral component separately, employing the methods described in 5.2 for the pure-tone components, and in 7.2 or annex D or E for the wideband component.

Step 3 If the initial spectrum is that of the sound at a source location, subtract each of the calculated atmospheric absorption attenuations from the separate discrete-frequency and wideband spectral components to obtain estimates for the sound pressure levels of the separate components of the spectrum at a receiver location, accounting for atmospheric-absorption losses alone. If the initial spectrum is that for a sound at a receiver location, add the calculated atmospheric-absorption attenuations to the sound pressure levels at the receiver to obtain estimates for the corresponding sound pressure levels at a source location, again accounting only for atmospheric absorption losses. If required, also subtract (or add) estimates for the attenuations by other mechanisms (e.g., wave divergence) to the frequency-band sound pressure levels of the initial spectrum.

Step 4 Combine the estimates for the time-mean-square sound pressures of the separate components of the spectrum to obtain the estimated band sound pressure levels of the composite spectrum at the receiver or source location.

8 Application to room acoustics

8.1 The reverberant sound field in a room decays, after the source of sound is stopped, at a rate that is the sum of (1) the decay rate d owing to absorption of sound on reflection from the boundaries of the room and the objects therein and (2) the decay rate owing to atmospheric absorption along propagation paths in the medium filling the room.

8.2 The decay rate in decibels per second of pure-tone sound pressure level in a room owing to absorption along propagation paths between reflections is the product of attenuation coefficient α in decibels per metre, from Eqs. (3), (4), and (5), and the speed of sound c, in metres per second, at the average air temperature in the room from Eq. (A5).

8.3 At a specified frequency, total decay rate D in decibels per second, for pure-tone sounds, from the combination of both surface and atmospheric absorption, is

$$D = d + \alpha c \tag{7}$$

8.4 Reverberation time T for sound pressure level decay in a room is frequently and appropriately defined as the time, in seconds, that *would* be required for the sound pressure level in the room to decay by 60 dB, after the sound source is stopped. It is related to total decay rate by

$$T = 60 / D \tag{8}$$

8.5 The relationships in Eqs. (7) and (8) may be utilized in analyses of reverberation-time measurements or, in design calculations, to determine the influence of atmospheric absorption on the total sound absorption in the room as a function of frequency under specified environmental conditions.

NOTES

1 Attenuation coefficients for atmospheric absorption from Table 1 may be used provided each tabulated value is first divided by 1000 to obtain coefficients in decibels per metre.

2 Analyses of atmospheric absorption in rooms excited by broadband sound analyzed by fractional-octave-band filters may consider one of the approaches described in clause 7 for evaluating the atmospheric absorption attenuation coefficient.

Annex A
(informative)

Physical mechanisms for atmospheric absorption

A1 Absorption mechanisms and frequency dependence

A1.1 Equation (5) in 5.2, for calculating the attenuation coefficient α resulting from atmospheric absorption, combines the contributions from a number of physical mechanisms into a form suitable for computation. However, understanding of the attenuation processes may be lost in the complexity of the formula. Formulae describing the contributions of the individual mechanisms are given in this annex to provide an understanding of what is covered by Eq. (5).

A1.2 Attenuation experienced by a sound wave propagating through the atmosphere, in excess of the attenuation attributable to wave divergence, is caused by shear viscosity, thermal conductivity, mass diffusion, thermal diffusion, and molecular relaxation. Attenuation by a molecular relaxation process is the result of an energy loss that occurs during the time required for a non-translational mode of energy storage (e.g., rotational or vibrational) within the molecules to adjust to changes in translational energy, as expressed by changes in temperature. This adjustment time introduces a time lag between sound pressure and density variations that results in attenuation of sound wave amplitude.

A1.3 Equations that describe the individual sound-absorption mechanisms were selected to reflect the best-available theoretical, rather than empirical, understanding of the physical processes. The constants in the equations were obtained from theory and from analysis of an extensive collection of laboratory measurements of atmospheric-absorption losses in air and in component gases.

A1.4 The attenuation coefficient α, in decibels per metre, is expressed by the sum of four terms as

$$\alpha = \alpha_{cl} + \alpha_{rot} + \alpha_{vib,O} + \alpha_{vib,N} \tag{A1}$$

where α_{cl} represents the absorption caused by the viscosity, heat conduction, and diffusion processes of "classical" physics, α_{rot} represents the molecular absorption caused by rotational relaxation, and $\alpha_{vib,O}$ and $\alpha_{vib,N}$ represent the molecular absorption caused by vibrational relaxation of oxygen and nitrogen molecules, respectively. (Within the accuracy limits specified in clause 6, the small contribution from carbon-dioxide vibrational relaxation is adequately accounted for in the vibrational relaxation terms for oxygen and nitrogen.)

A1.5 The portion of the attenuation coefficient owing to classical and rotational absorption is given in decibels per metre, to a close approximation for air temperatures of concern to this Standard, by their sum α_{cr} according to

$$\alpha_{cr} = \alpha_{cl} + \alpha_{rot} = \left[1.60 \times 10^{-10}\left(\frac{T}{T_r}\right)^{1/2} f^2\right]\left(\frac{p_a}{p_r}\right)^{-1} \tag{A2}$$

where the reference pressure p_r and reference temperature T_r are given in 3.2.

A1.6 The two vibrational relaxation terms in Eq. (A1) have the same form, namely

$$\alpha_{vib,O} = \left[(\alpha\lambda)_{max,O}\right]\left(\frac{f}{c}\right)\left(\frac{2 f_{rO} f}{f_{rO}^2 + f^2}\right) \tag{A3}$$

and

$$\alpha_{vib,N} = \left[(\alpha\lambda)_{max,N}\right]\left(\frac{f}{c}\right)\left(\frac{2 f_{rN} f}{f_{rN}^2 + f^2}\right) \tag{A4}$$

where the constituent subscript is O for oxygen and N for nitrogen relaxations; c is the speed of sound in metres per second, f_r is a relaxation frequency in hertz, and $(\alpha\lambda)_{max}$ is the maximum absorption, in decibels, caused by vibrational relaxation over a distance of one wavelength λ in metres.

A1.7 Formulae for the oxygen and nitrogen relaxation frequencies are given by Eqs. (3) and (4) in 5.2. The analytical forms for the relaxation frequencies are based upon rigorous theoretical treatment of the microscopic energy-transfer processes that govern vibrational relaxation. The constants that appear in the analytical expressions in Eqs. (3) and (4) were selected to yield best agreement between computed relaxation frequencies and relaxation frequencies determined from laboratory test results.

A1.8 For the purpose of this Standard, the speed of sound c in Eqs. (A3) and (A4), in metres per second, is computed from

$$c = 343.2\left(T / T_r\right)^{1/2} \qquad \text{(A5)}$$

NOTE – Equation (A5) neglects the small effect of water vapor on the speed of sound If required, the effect of water vapor on the speed of sound may be accounted for by the following modification of Eq (A5) c = 343 2(1 + 0.0016 h)$(T/T_r)^{1/2}$, where h is the molar concentration of water vapor in percent.

A1.9 The maximum atmospheric absorption in a distance of one wavelength, $(\alpha\lambda)_{max}$, as a result of vibrational relaxation, depends only on the temperature of the air and has the same form for both oxygen and nitrogen relaxation. It is determined, in decibels, from

$$(\alpha\lambda)_{max,O} = 1.559\, X_O\left(\Theta_O / T\right)^2 \exp(-\Theta_O / T) \qquad \text{(A6)}$$

and

$$(\alpha\lambda)_{max,N} = 1.559\, X_N\left(\Theta_N / T\right)^2 \exp(-\Theta_N / T) \qquad \text{(A7)}$$

where Θ is the characteristic vibrational temperature and X is the nondimensional fractional molar concentration (in dry air) of oxygen (subscript O) and of nitrogen (subscript N).

A1.10 For the purposes of this Standard, the characteristic vibrational temperatures and the fractional molar concentrations have the following values: Θ = 2239.1 K for oxygen and 3352.0 K for nitrogen; X = 0.209 for oxygen and 0.781 for nitrogen, see 3.1. The constant 1.559 in Eqs. (A6) and (A7) was obtained from the theoretical expression $(2\pi/35)[10 \lg(e^2)]$.

A1.11 Equation (5) in 5.2 is obtained by substituting Eqs. (A2) through (A7) in Eq. (A1).

A2 Pressure dependence

A2.1 Attenuation coefficients α_1 from Table 1 for an atmospheric pressure equal to the reference atmospheric pressure p_r of one standard atmosphere may be scaled to the attenuation coefficient α_2 for any other atmospheric pressure p_a by application of the linear pressure-dependency relationship for atmospheric absorption that is inherent in molecular collision processes. The pressure-scaling procedure is described in the next paragraphs.

A2.2 Dividing the portion from Eq. (A2) of an attenuation coefficient owing to classical plus rotational losses, α_{cr} in decibels per metre, by a nondimensional atmospheric pressure $p^* = (p_a/p_r)$, as a fraction of a standard atmosphere, yields the general pressure-scaled expression for this component

$$(\alpha_{cr} / p^*) = (K_1)(f / p^*)^2 \qquad \text{(A8)}$$

in decibels per (metre-atmosphere) with K_1 the temperature-dependent constant from Eq. (5).

A2.3 The portion of the attenuation coefficient owing to vibrational relaxation losses, $\alpha_{vib,i}$ in decibels per metre for oxygen (i = O) or nitrogen (i = N), is strongly dependent on the corresponding relaxation frequency $f_{r,i}$ for each constituent. However, each relaxation frequency varies directly with the atmospheric pressure [see Eqs. (3) and (4)] and is also a function of molar concentration of water vapor h.

A2.4 From Eq. (B1), molar concentration of water vapor may be expressed in terms of a pressure-scaled relative humidity (h_{rel} / p^*) in percent per atmosphere according to

$$h = (K_2)(h_{rel} / p^*) \qquad \text{(A9)}$$

where K_2 is the temperature-dependent ratio of the saturation vapor pressure to the reference atmospheric pressure, from Eq. (B2a) or (B3a).

A2.5 Each relaxation frequency may be expressed as a pressure-scaled relaxation frequency that is a function of pressure-scaled relative humidity. This formulation is denoted here as $F_{r,i}$ (h_{rel} / p^*), in hertz per atmosphere, and determined according to

$$(f_{r,i} / p^*) = F_{r,i}\,(h_{rel} / p^*) \qquad \text{(A10)}$$

A2.6 Thus, dividing Eq. (3) or (4) by the atmospheric pressure ratio p^*, the pressure-scaled vibrational-relaxation component, for the oxygen and nitrogen terms in the attenuation coefficient, may be expressed in general form as

$$(\alpha_{\mathrm{vib},i} / p^*) = \frac{(K_{3i})(f / p^*)^2 [F_{r,i}(h_{rel} / p^*)]}{F_{r,i}^2 (h_{rel} / p^*) + (f / p^*)^2} \qquad \text{(A11)}$$

where K_{3i} is the temperature-dependent constant for the *i*-th component from Eq. (5).

A2.7 Utilizing the additive relationship from Eq. (A1) for the separate loss mechanisms yields the following expression for the total pressure-scaled attenuation coefficient

$$(\alpha / p^*) = \Gamma[(f / p^*), (h_{rel} / p^*)] \qquad \text{(A12)}$$

where $\Gamma[(f / p^*), (h_{rel} / p^*)]$ is a general temperature-dependent function for a total pressure-scaled attenuation coefficient which in turn depends on pressure-scaled frequency (f / p^*), in hertz per atmosphere, and pressure-scaled relative humidity (h_{rel} / p^*), in percent per atmosphere.

A2.8 For a given air temperature, for two different atmospheric pressures p_1^* and p_2^* in atmospheres, the two pressure-scaled attenuation coefficients (α_1 / p_1^*) and (α_2 / p_2^*) will be the same for the same values of pressure-scaled frequency (f / p^*) and pressure-scaled relative humidity (h_{rel} / p^*).

A2.9 As an example, apply the pressure-scaling concept to determine the pure-tone attenuation coefficient at a temperature of 293.15 K (20 °C), relative humidity of 40%, nominal frequency of 1000 Hz, and an atmospheric pressure of 0.5 standard atmospheres.

Pressure-scaled relative humidity is 40/0.5 = 80 percent/atmosphere. Pressure-scaled frequency is 1000/0.5 = 2000 hertz/atmosphere. From Table 1(j), the pressure-scaled attenuation coefficient (α_1 / p_1^*) is 8.98 dB/(km•atmosphere) at 20 °C, nominal frequency of 2000 Hz, and relative humidity of 80%.

The actual attenuation coefficient α_2 at 1000 Hz, 40% relative humidity, and a pressure of 0.5 atmospheres is then found from $(\alpha_1 / p_1^*)(p_2^*) = 8.98 \times 0.5 = 4.49$ dB/km.

A2.10 The pressure-scaling concept described here is subject to two constraints when utilized with the attenuation coefficients in Table 1:

(1) pressure-scaled relative humidities greater than 100% are not available from the table; and

(2) the differences between exact frequencies as calculated from Eq. (6) and the nominal frequencies listed in the table introduce errors of the order of 1% if the nominal frequencies instead of the exact frequencies are used.

The above two constraints may be avoided if Eqs. (3) to (5) and Eqs. (B1) and (B2), or (B3), instead of Table 1 are employed to compute attenuation coefficients for any atmospheric pressure.

Annex B
(informative)

Conversion of humidity data to molar concentration of water vapor

B1 Introduction

This annex provides analytical expressions, not readily available in the literature, to calculate the molar concentration of water vapor from measurements or specification of relative humidity or dewpoint. Other measures of humidity should first be converted to relative humidity and then to molar concentration.

B2 Relative humidity

For a sample of moist air at a given temperature, relative humidity is the ratio, expressed as a percentage, of the vapor pressure of water in the moist air to the saturation vapor pressure p_{sat} with respect to a plane surface of liquid water at the same temperature and pressure that characterize the sample of moist air. For a given temperature and pressure, molar concentration h of water vapor, in percent, may be calculated, for a specified relative humidity h_{rel}, in percent, from

$$h = h_{rel}\left(\frac{p_{sat}}{p_r}\right)\left(\frac{p_a}{p_r}\right)^{-1} \tag{B1}$$

where p_a is the prevailing atmospheric pressure in kilopascals and p_r is the reference atmospheric pressure of 101.325 kPa from 3.2.

NOTE – By convention, relative humidity at air temperatures less than 0 °C is evaluated with respect to saturation over a surface of liquid water, not ice or frost.

B3 Saturation vapor pressure

B3.1 The saturation vapor pressure p_{sat} of aqueous vapor over a plane surface of liquid water is a function solely of air temperature T. The following definitive equation (employed for the calculations of attenuation coefficients in Table 1) provides the ratio of saturation vapor pressure to the reference atmospheric pressure.

$$\frac{p_{sat}}{p_r} = 10^{V} \tag{B2a}$$

with exponent V given by

$$\begin{aligned} V = {} & 10.79586\left[1-\left(\frac{T_{01}}{T}\right)\right] \\ & -5.02808 \lg\left(\frac{T}{T_{01}}\right) \\ & +1.50474\times10^{-4}\left\{1-10^{-8.29692\left[(T/T_{01})-1\right]}\right\} \\ & +0.42873\times10^{-3}\left\{-1+10^{4.76955\left[1-(T_{01}/T)\right]}\right\} \\ & -2.2195983 \end{aligned} \tag{B2b}$$

Temperature T is in kelvins and T_{01} is the triple-point isotherm temperature of 273.16 K (i.e., +0.01 °C).

B3.2 The following equation provides a close approximation to the ratio, calculated by means of Eq. (B2), of saturation vapor pressure to the reference atmospheric pressure.

$$\frac{p_{sat}}{p_r} = 10^{C} \tag{B3a}$$

with exponent C given by

$$C = -6.8346\left(\frac{T_{01}}{T}\right)^{1.261} + 4.6151 \tag{B3b}$$

B3.3 To find h for given T, p_a, and h_{rel}, first find the value of the ratio p_{sat}/p_r by use of Eq. (B2) or (B3) for the air temperature. Then, find h by use of Eq. (B1) for the given relative humidity in percent and atmospheric pressure in kilopascals.

B4 Dewpoint

B4.1 The dewpoint temperature T_D of a sample of moist air, at temperature T, pressure p_a, and molar concentration h, is the equilibrium temperature to which the sample must be cooled to be saturated over a surface of liquid water at the same given pressure.

B4.2 To calculate the molar concentration of water vapor, given a measurement of dewpoint for some air temperature, first determine the saturation vapor pressure ratio p_{sat}/p_r at the dewpoint T_D by use of Eq. (B2) or (B3) with T_D for temperature T. Then determine the molar concentration by use of Eq. (B1) for the ratio of the given atmospheric pressure p_a to the standard air pressure with relative humidity h_{rel} equal to 100 percent.

NOTE – Measurements of dewpoints at low air temperatures may yield frostpoints, corresponding to saturation over a surface of ice instead of supercooled water. Due account for the conventional definition of relative humidity should be considered when frostpoints are measured. Equations (B2) and (B3) apply only for saturation vapor pressures over liquid water, not ice or frost.

B4.2.1 As an example calculation, assume an air pressure of 95.0 kPa (i.e., 950 hectopascals or 950 millibars) and a dewpoint of 290.15 K (i.e., +17 °C). Equation (B2) gives the saturation vapor pressure ratio at the dewpoint as 0.01911. From Eq. (B1), the molar concentration for those conditions is then

$$h = 100(0.01911)(95.0/101.325)^{-1} = 2.038\,\%$$

to four figures.

B4.3 Alternatively, the relative humidity, in percent, of a sample of moist air may be determined from a measurement of dewpoint and air temperature by use of the following relationship for moist air at constant pressure

$$h_{rel} = 100\left[\frac{(p_{sat,T_D}/p_r)}{(p_{sat,T}/p_r)}\right] \tag{B4}$$

Equation (B1) may then be applied to determine the molar concentration.

B4.3.1 For a dewpoint example calculation, assume a dewpoint T_D of 287.55 K (or +14.4 °C) for an air temperature T of 294.45 K (or +21.3 °C). From Eq. (B2), the saturation vapor pressure ratios at the dewpoint and air temperatures are 0.01618 and 0.02499, respectively. To four figures, relative humidity by Eq. (B4) is then 100(0.01618)/(0.02499) or 64.75%. With h_r = 64.75% and p_{sat}/p_r = 0.02499, for p_a/p_r = 1, the molar concentration of water vapor by Eq. (B1) is (64.75)(0.02499)(1) = 1.618%.

Annex C
(informative)
Effect of inhomogeneous, real atmospheres

C1 Introduction

In the main body of this Standard, the atmosphere through which a sound propagates has been assumed to be uniform along the sound propagation path; that is, the pressure, temperature, and molar concentration of water vapor could each be specified by single, fixed numbers. The effects on pure-tone attenuation coefficients of variation in the meteorological variables during propagation through an inhomogeneous real atmosphere are considered in this annex.

C2 Variation with altitude

C2.1 The vertical profile of mean annual molar concentration of water vapor h_m (as a percentage) in Table C1 was constructed to be consistent with the vertical profiles from ISO 2533 of mean annual temperature T_m (in kelvins) and pressure p_m (in kilopascals) at mid-latitudes near 45-degrees North. Subscript m is used in this annex to denote mean annual values.

C2.2 The following equations specify profiles of air temperature, atmospheric pressure, and mean-annual molar concentration of water vapor over two ranges of geopotential height H (in kilometres) from 0 to 11 km (the troposphere), and from 11 km to 20 km (the stratosphere).

a) For sea level to 11 km:

$$T_m = T_{ms} - 6.5\,H \tag{C1}$$

$$p_m = p_{ms}\left(T_m / T_{ms}\right)^{5.25588} \tag{C2}$$

$$h_m = A_0 \times 10^{G_1} \tag{C3}$$

where

$$G_1 = A_1 H + A_2 H^2 + A_3 H^3 + A_4 H^4 + A_5 H^5 + A_6 H^6$$

and

b) for 11 km to 20 km:

$$T_m = 216.65 \tag{C4}$$

$$p_m = 22.632 \exp[-0.157688\,(H-11)] \tag{C5}$$

$$h_m = A_7 \times 10^{G_2} \tag{C6}$$

where

$$G_2 = A_8 H + A_9 H^2 + A_{10} H^3 + A_{11} H^4 \ .$$

C2.3 The equations for the variation of air temperature and atmospheric pressure are from ISO 2533. The empirical expressions for molar concentration were developed from extensive measurements. Mean annual temperature T_{ms} and mean annual atmospheric pressure p_{ms}, at mean sea level (where $H = 0$), have the standard values specified in ISO 2533 of 288.15 K and 101.325 kPa, respectively.

C2.4 The 11 constants are:

$A_0 = 1.00271$;	$A_1 = -0.12223$;
$A_2 = 0.04546$;	$A_3 = -0.031545$;
$A_4 = 0.0076472$;	$A_5 = -0.00079906$;
$A_6 = 0.000029429$;	$A_7 = 1.8395 \times 10^{-20}$;
$A_8 = 5.44894$;	$A_9 = -0.60683$;
$A_{10} = 0.0283643$;	$A_{11} = -0.000474746$.

C2.5 The pure-tone attenuation coefficients for atmospheric absorption shown in Table C1 were calculated for the above atmospheric parameters by use of Eqs. (3) to (5) with exact midband frequencies calculated from Eq. (6). Note the large variation in the mean annual attenuation with altitude for all frequencies.

C3 Local variation

C3.1 The local variations of atmospheric pressure, air temperature, and humidity from the mean annual values shown in Table C1 are complex. The effects of these variations in meteorological conditions on atmospheric absorption are summarized in the following subclauses.

Table C1 — Dependence of temperature T_m, pressure p_m, molar concentration of water vapor h_m, and pure-tone attenuation coefficient α_m, at mid-latitudes, on geopotential altitude H above mean sea level.

				α_m, mean-annual attenuation coefficient (dB/km)							
H	T_m	p_m	h_m	nominal octave midband frequency (kHz)							
(km)	(K)	(kPa)	(%)	0.063	0 125	0.25	0 5	1	2	4	8
0	288 15	101.325	1.00271	0.12	0.43	1.18	2.30	4.06	9.53	30.48	109 03
0.5	284 90	95.461	0.88702	0.13	0.44	1.10	2.02	3.81	10.04	34.01	121.27
1	281 65	89 875	0.79385	0.14	0 43	1.00	1.79	3.70	10.76	37.76	132.05
2	275.15	79.495	0.60935	0.15	0.40	0 79	1.53	4 02	13 61	48.49	151.09
3	268.65	70.109	0.43513	0.15	0.34	0 66	1.65	5.41	19 26	61.61	143.83
4	262.15	61.640	0.30250	0.14	0.29	0.70	2 27	8.03	25.81	60.50	99.20
5	255.65	54 020	0.21167	0.12	0.30	0.96	3.38	10.87	25.46	40.67	58.97
6	249.15	47.181	0 14486	0.14	0 43	1.48	4.68	10.62	16.26	21 95	37.47
7	242 65	41.061	0.08843	0.22	0.74	2.14	4.16	5 66	7.17	11.55	28.53
8	236 15	35.600	0.04322	0.43	0 90	1 26	1 48	1.82	3.05	7.89	27.19
9	229.65	30.742	0.01646	0 26	0.30	0.33	0.42	0.77	2 16	7 69	29 72
10	223.15	26.436	0 00595	0.10	0.11	0 13	0 24	0.64	2 23	8.57	33.82
11	216.65	22 632	0 00380	0.06	0.07	0.10	0.21	0.67	2.51	9.81	38.87
12	216.65	19 330	0.00274	0 05	0 06	0 09	0.23	0.77	2.91	11.46	45.49
13	216.65	16 510	0.00201	0.04	0 05	0 09	0.25	0.88	3 39	13.40	53 24
14	216.65	14.102	0.00160	0.03	0.05	0.09	0.28	1.02	3.96	15.68	62.32
15	216.65	12.045	0.00144	0.03	0.04	0.10	0.32	1.18	4 63	18.34	72.95
16	216.65	10 287	0.00147	0.03	0.04	0.11	0.36	1.37	5.41	21.47	85.41
17	216 65	8.787	0.00168	0 03	0.04	0.12	0.42	1.60	6.33	25.13	99.99
18	216 65	7 505	0.00207	0.02	0.05	0.13	0.48	1.87	7.40	29.42	117.06
19	216 65	6.410	0.00257	0.02	0 05	0.15	0.56	2.19	8.66	34.44	137.05
20	216.65	5.475	0.00293	0.02	0.05	0.17	0.65	2.56	10.14	40.31	160.45

NOTE – Attenuation coefficients were calculated for mean annual air temperatures, atmospheric pressures, and molar concentrations of water vapor determined from Eqs. (C1) to (C6) and for the exact midband frequencies corresponding to the eight nominal octave midband frequencies from 63 Hz to 8 kHz. Subscript m denotes mean annual conditions.

C3.2 For a given altitude or height above sea level, variations in atmospheric pressure are rarely greater than ±5% of the pressure shown in Table C1. A ±5% variation in atmospheric pressure will cause less than ±5% variation in attenuation coefficient. Therefore, for most applications, deviations from the mean profile of atmospheric pressure in Table C1 may be ignored.

C3.3 For a given altitude, there are large variations with time and place in air temperature and molar concentration of water vapor. For example, the range of variation near the ground is comparable to that shown in Table C1 for the mean variation with altitude. As a result, for calculations of attenuation by atmospheric absorption, there is no substitute for local information concerning temperature and molar concentration for the time and place for which the calculation is made.

C3.4 Usually, however, meteorological information is limited to time averages measured at (or forecast for) one place near the surface of the ground, often for a height of approximately 10 m. The time-averaged data leave the user with the problem of judging how representative they may be for conditions along a sound propagation path at a particular time.

C3.5 When meteorological information is limited to surface data, two facts should be recognized:

a) the atmospheric variable that dominates the behavior of atmospheric absorption according to Eqs. (3) to (5) is the molar concentration of water vapor; and

b) molar concentration of water vapor (or dewpoint) tends to be constant throughout the boundary layer closest to the earth during normal daytime hours because of the mixing of the atmosphere which occurs as a result of the action of winds.

C3.6 If the sound propagation path is well within the mixed layer, attenuation from atmospheric absorption may be calculated with accuracy suitable for many applications by use of meteorological measurements near the ground, under the assumption that molar concentration is constant to the height of the top of the mixed layer. The thickness of the mixed layer may vary from approximately 10 m at night to approximately 1 km on a sunny afternoon in summer. When this thickness is in doubt, measurements of meteorological conditions aloft should be obtained or expert advice consulted to determine a suitable model for the atmosphere.

C3.7 If an average atmospheric absorption is to be determined for a range of local weather conditions near the ground and aloft, the attenuation coefficients for each condition should be calculated and then arithmetically averaged rather than first averaging the weather conditions and then calculating the attenuation coefficients.

C3.8 For specified meteorological conditions, the total pure-tone attenuation over a sound-propagation path may be determined from a summation of the pure-tone attenuations over segments of the path by a procedure similar to that described in annex E.

Annex D
(informative)

General spectrum-integration method for calculating the attenuation by atmospheric absorption of wideband sounds analyzed by fractional-octave-band filters

D1 Introduction

D1.1 This annex describes a general spectrum-integration method to calculate the attenuation by atmospheric absorption applicable to fractional-octave-band sound pressure levels. The spectrum of the sound is assumed to be continuous and wideband without significant discrete-frequency components. The method may be applied to various practical situations without the limitations given in 7.1.3 and 7.1.5.

D1.2 A user of the general method described in this annex should be aware of practical limitations regarding such matters as the additional time required to carry out the computations and the fact that some sound pressure levels that might be calculated (or which should have been measured) may in fact not be measurable with commercially available instruments because of limitations imposed by ambient background sounds, the electrical noise floor of the instruments, or the effects introduced by the use of practical bandpass filters (see the discussion in 7.1.2). On the other hand, the method described in this annex, while more complicated than the approximate pure-tone method described in 7.2, can yield more-accurate estimates for fractional-octave-band sound pressure levels than the pure-tone method.

D1.3 The general features of the calculation method are described for three cases. For Case 1, band sound pressure levels are known at the location of a sound source and band sound pressure levels are to be determined at the location of a distant receiver. For Case 2, band sound pressure levels are known at a receiver and corresponding band sound pressure levels are to be determined at the source of sound. For Case 3, band sound pressure levels are known at a receiver for one set of meteorological conditions along the sound propagation path and the band sound pressure levels are to be determined that would have been measured at the same location but under different meteorological conditions. For all cases, the calculation method described in this annex is limited to attenuation by atmospheric-absorption processes. Attenuation by other mechanisms is neglected.

D1.4 The analytical procedures described in this annex assume that the bandpass filters were designed according to the base-10 system for mid-band and bandedge frequencies; see Eq. (6).

D2 Case 1: Band sound pressure levels known at the source

D2.1 The fractional-octave-band sound pressure level $L_{BR}(f_m)$, (in decibels and relative to the standard reference sound pressure p_0 = 20 μPa), at receiver location R and after attenuation from atmospheric absorption over the path from the source to the receiver, may be calculated from

$$L_{BR}(f_m) = 10\lg\left(\left\{\int_{f_L}^{f_U} 10^{0.1[L_S(f)-\delta L_t(f)-\Delta A(f)]}\mathrm{d}f\right\} / B_0\right) \tag{D1}$$

where $L_S(f)$ is the pressure spectrum level, in decibels, (relative to p_0^2/B_0 with B_0 equal to the normalizing bandwidth of 1 Hz) of the sound at the source, $\delta L_t(f)$ is the pure-tone attenuation, in decibels, from atmospheric absorption over the total length of the sound-propagation path from the source to the receiver at any frequency f between the effective lower and upper frequency limits for integration, f_L and f_U in hertz, and $\Delta A(f)$ is the filter's relative-attenuation response, in decibels, of the filter employed for analysis of both source and receiver signals; see IEC 1260.

D2.2 For given meteorological conditions and sound-propagation path, if analytical functions were available to describe the pressure spectrum level, total pure-tone attenuation, and filter relative-attenuation response as continuous functions of frequency, Eq. (D1) could, in principle, be evaluated in closed form. In practice, the integral is evaluated numerically by a summation over a range of frequency in the lower transition band, passband, and upper transition band of a filter's attenuation response, with the three elements of the integrand specified at discrete frequencies.

D2.3 In many cases of practical interest, the pressure spectrum level of the sound source, $L_S(f)$, may be considered to be smooth and essentially independent of frequency. For those cases, the pressure spectrum level of the sound source may be estimated from frequency-band sound pressure levels $L_{BS}(f_m)$ measured or predicted for the effective location of the sound source under specified operating conditions.

If no better estimate is available, the pressure spectrum level of the sound from the source may be estimated at the midband frequency of each filter band by subtracting a correction for the bandwidth of the corresponding ideal bandpass filter.

Thus,

$$L_S(f) = L_{BS}(f_m) - 10\,\lg(B_i / B_0) \qquad \text{(D2)}$$

where the exact bandwidth, B_i in hertz, of the corresponding ideal filter is given by

$$B_i = f_2 - f_1 = (f_m)[10^{3/(20b)} - 10^{-3/(20b)}] \qquad \text{(D3)}$$

and where f_2 and f_1 correspond to the upper and lower exact band-edge frequencies, and (1/b) is the bandwidth designator described in NOTE 1 to 5.4.3.

D2.4 If the spectrum of the sound-pressure signal contains both wideband and significant discrete-frequency components, the procedures described in 7.3 may first be employed to determine estimates for the separate components of the composite spectrum. For the discrete-frequency components, follow the procedure of clause 5 to determine the attenuation. In this case, the ideal-filter bandwidth correction of Eq. (D2) should be subtracted from the indicated band sound pressure level only after following Step 1 of 7.3 to remove discrete-frequency components.

D2.5 For the wideband component of the spectrum, the pressure spectrum level at any frequency between successive midband frequencies may be estimated by suitable interpolation between successive estimates of the pressure spectrum levels at the exact midband frequencies to yield estimated pressure spectrum levels for $L_S(f)$ at each desired frequency. An application-specific protocol is needed to estimate pressure spectrum levels at frequencies below or above the lower and upper band-edge frequencies of the lowest and highest frequency bands, respectively.

D2.6 If the meteorological conditions are uniform over the sound propagation path from the source to the receiver, the pure-tone attenuation $\delta L_t(f)$ may be readily calculated at any frequency by application of the procedure indicated by Eqs. (3) to (5). For air-to-ground sound propagation, if the meteorological conditions over the propagation path are not uniform, the atmosphere should be modeled as a stack of N horizontal layers preferably with average attenuation coefficients specified for the thickness of each layer.

D2.7 For each frequency required to carry out the integration of Eq. (D1) for each filter band, and for each discrete-frequency component that may be present, the total pure-tone atmospheric absorption attenuation over the entire sound propagation pathlength from the source to the receiver is found from a summation of the average pure-tone attenuations $\delta L_{tn}(f)$ in the N layers according to

$$\delta L_t(f) = \sum_{n=1}^{N} \delta L_{tn}(f) \qquad \text{(D4)}$$

D2.8 The relative-attenuation response (i.e., filter attenuation at any frequency minus the passband reference attenuation specified by the manufacturer) is preferably determined experimentally for each filter band or supplied by the manufacturer. Alternatively, analytical representations of the relative-attenuation response of a selected filter design may be utilized for evaluation of Eq. (D1). The filter manufacturer should be consulted for advice on analytical representations for the relative-attenuation responses of the bandpass filters in a spectrum analyzer.

D2.9 The remaining items that need to be specified in order to evaluate the integral in Eq. (D1) are the frequency limits and the size of the steps in a numerical integration between the lower and upper limits.

D2.10 The relative-attenuation response of many practical filters is not symmetric nor the same for each filter band in a set of fractional-octave-band filters; the rate of change of attenuation with increasing frequency is often more rapid in the upper transition band (i.e., from the passband toward the high-attenuation region of the upper stopband) than it is in the lower transition band.

In addition, for frequencies in the range from about 25 Hz to 1 kHz, the slope of the pressure spectrum level of many wideband sound sources often is either slightly positive with increasing frequency or is nearly independent of frequency.

At high frequencies (e.g., above approximately 1 kHz), the slope of the wideband pressure spectrum level is often negative. For those reasons, for general applications it is recommended that the frequency limits in Eq. (D1) be set to

$$f_L = (1/5)f_1 \text{ and } f_U = 2f_2 \tag{D5}$$

for filter bandwidths not exceeding one octave.

Specific situations may require that the limits of integration be set to encompass a wider or narrower range of frequencies than from one fifth of f_1 to twice f_2. Exact band-edge frequencies f_1 and f_2 should be calculated as indicated by Eq. (D3) for the applicable bandwidth designator, 1/b, and exact midband frequency, f_m, from Eq. (6).

D2.11 For numerical integration of Eq. (D1), the size of the frequency steps should be chosen with care. In the lower and upper transition bands from f_L to f_1 and from f_2 to f_U respectively, where the relative-attenuation response of the filter changes rapidly with frequency, the interval between successive frequencies should be not larger than $[10^{3/(240b)}]f_m$, i.e., approximately 1/72-nd of an octave for one-third-octave-band filters for which the bandwidth designator 1/b = 1/3. In the passband between f_1 and f_2 where the relative-attenuation response of a bandpass filter is approximately constant, the interval between successive frequencies may be increased to $[10^{3/(80b)}]f_m$, i.e., approximately 1/24-th of an octave for one-third-octave-band filters.

D3 Case 2: Band sound pressure levels known at a receiver location

D3.1 For case 2, the fractional-octave-band sound pressure level $L_{BS}(f_m)$, in decibels, at source location S and considering only attenuation from atmospheric absorption over the path from the receiver to the source, may be calculated from a modified version of Eq. (D1) using

$$L_{BS}(f_m) = 10 \lg\left(\left\{\int_{f_L}^{f_U} 10^{0.1[L_R(f)+\delta L_t(f)-\Delta A(f)]} df\right\} / B_0\right) \tag{D6}$$

where the sign of $\delta L_t(f)$ is positive instead of negative as in Eq. (D1) to indicate an increase in the sound pressure level along the path from the receiver back to the source.

D3.2 The pressure spectrum levels at the receiver have to be determined with special care because measured band sound pressure levels will include, by necessity, the effect of the filters used for the analysis (see the discussion in 7.1.2).

D3.3 An approximate method to determine the pressure spectrum level of the sound at the receiver is to subtract the ideal-filter bandwidth correction, given in Eq. (D2), from the band sound pressure levels at the receiver.

However, because the slope of the pressure spectrum level often changes much more rapidly with frequency at a receiver location than at a source location (especially at frequencies greater than 1 kHz), careful consideration should be given to the procedure selected to interpolate values for pressure spectrum level at frequencies between the midband frequencies. Linear interpolation of the pressure spectrum levels between midband frequencies may not be suitable for midband frequencies greater than approximately 2 kHz.

Pressure spectrum levels should not be extrapolated to frequencies greater than the upper band-edge frequency of the highest midband frequency of the measured band sound pressure levels at the receiver, nor lower than the lower band-edge frequency of the lowest frequency band.

D3.4 If the band sound pressure levels at the receiver represent data measured over a long sound-propagation distance or under highly absorptive conditions, or both, the indicated band sound pressure levels in the high-frequency bands often are contaminated by contributions from the electrical noise floor of the instruments. In addition, sound-pressure signals from ambient sound sources (i.e., not from the sound source of interest) may contribute to the background noise. For those cases, the band sound pressure levels of the actual signal from the source were not measured and the contaminated band sound pressure levels should be removed from the analysis to avoid calculation of spurious band sound pressure levels at the source. Alternatively, an appropriate extrapolation procedure may be utilized to provide estimates for band sound pressure levels that are missing because of contamination.

NOTE – Because of the rapid increase of atmospheric absorption with frequency, linear extrapolation of the non-contaminated band sound pressure levels to higher frequencies is not recommended. One possible extrapolation method is to assume that the spectrum of the sound source is uniform across the frequency range of each bandpass filter.

Estimates for band sound pressure levels in those frequency bands where the indicated band sound pressure level is irretrievably contaminated by background noise may be obtained by successive application of the following relation

$$L_{BR}(f_{i+1}) = L_{BR}(f_i) - [\delta L_t(f_{i+1}) - \delta L_t(f_i)] \qquad \text{(D7)}$$

where $L_{BR}(f_{i=1})$ is the sound pressure level in the last good band.

Pure-tone attenuations, in decibels, $\delta L_t(f_{i+1})$ and $\delta L_t(f_i)$, are at exact midband frequencies f_{i+1} and f_i, respectively, and for average meteorological conditions over the entire sound-propagation pathlength. Extrapolation by the method of Eq (D7) continues from the last good band to successively higher frequencies until a complete set of band sound pressure levels is obtained.

D3.5 After an appropriate estimate has been determined for the pressure spectrum level of the sound at the receiver and for the total pure-tone atmospheric absorption attenuation along the path as a continuous function of frequency (see D2.7), the calculations for Eq. (D6) proceed as described for Case 1 with band sound pressure levels known at a source. However, a calculation of a band sound pressure level should not be attempted when the magnitude of the negative slope of the estimated pressure spectrum level across the frequency range of integration for the lower transition band of a filter (generally a high-frequency band) approaches, or exceeds, the magnitude of the positive slope of the filter's relative-attenuation characteristic in the corresponding lower transition band.

D4 Case 3: Adjusting measured sound pressure levels at a receiver location for differences in attenuation by atmospheric absorption resulting from different meteorological conditions along a sound-propagation path

D4.1 The following expression may be applied to adjust fractional-octave-band sound pressure levels $L_{BR1}(f_m)$ measured at a receiver under meteorological condition 1 (e.g., test-day conditions) to band sound pressure levels $L_{BR2}(f_m)$ that would have been measured under meteorological condition 2 (e.g., reference meteorological conditions)

$$L_{BR2}(f_m) = 10\lg\left(\left\{\int_{f_L}^{f_U} 10^{0.1\left[L_{BR1}(f)+\delta L_{t1}(f)-\delta L_{t2}-\Delta A(f)\right]} df\right\} / B_0\right) \qquad \text{(D8)}$$

where $L_{BR1}(f)$ and $\delta L_{t1}(f)$ are the pressure spectrum level of the sound at the receiver and the total pure-tone atmospheric-absorption attenuation under meteorological condition 1, and $\delta L_{t2}(f)$ is the total pure-tone atmospheric-absorption attenuation under meteorological condition 2.

D4.2 The procedure for evaluating the integral in Eq. (D8) proceeds as described for evaluation of the corresponding expressions for Cases 1 and 2, once the input quantities are specified. Special attention should be given to the remarks in D3.4 and D3.5.

Annex E
(informative)

Approximate method for calculating the attenuation by atmospheric absorption of wideband sounds analyzed by fractional-octave-band filters

E1 Introduction

E1.1 This annex provides an approximate method to calculate fractional-octave-band sound pressure levels at a receiver or source location, or to adjust such band sound pressure levels measured at a receiver location for the effects of different meteorological conditions along the sound propagation path.

E1.2 The approximate method of this annex may be substituted for the general spectrum-integration method described in annex D when the calculated total pure-tone attenuation over the total pathlength is less than 50 dB at any exact midband frequency. Under the 50-dB limitation, for one-third-octave-band filters, the value of a calculated pathlength attenuation should be within ±5% of the attenuation that would have been determined by the method of annex D.

E1.3 Applications of the approximate method described in this annex should consider the cautionary remarks in annex D concerning the measurement of sound pressure levels when the sound-propagation pathlengths are long, or the frequency is high, or both.

E1.4 As in annex D, the calculation method described in this annex is limited to attenuation by atmospheric-absorption processes. Attenuation by other mechanisms such as reflection and refraction in non-homogeneous atmospheres is not included.

E1.5 The approximate calculation method described in this annex assumes that the bandpass filters were designed according to the base-10 system for midband and band-edge frequencies; see Eqs. (6) and (D3).

E2 General approach

E2.1 For the case 1 described in annex D, when a fractional-octave-band sound pressure level $L_{BS}(f_k)$ is known at a sound-source location S, the sound pressure level $L_{BR}(f_k)$ at a receiver location R, in the same fractional-octave-band with nominal midband frequency f_k, is found from

$$L_{BR}(f_k) = L_{BS}(f_k) - \delta L_B(f_k) \tag{E1}$$

where $\delta L_B(f_k)$ is the band-level attenuation determined in accordance with this annex and applicable to the meteorological conditions along the sound-propagation path and bandwidth of the fractional-octave filter.

E2.2 Similarly, for case 2 when a fractional-octave-band sound pressure level $L_{BR}(f_k)$ is known at the location of a sound receiver, the sound pressure level $L_{BS}(f_k)$ at the source, in the same fractional-octave-band with nominal midband frequency f_k, is found from

$$L_{BS}(f_k) = L_{BR}(f_k) + \delta L_B(f_k) \tag{E2}$$

E2.3 For the third case described in annex D, the band-level attenuation associated with the effects of different attenuation by atmospheric absorption over the length of a sound-propagation path as a result of different meteorological conditions 1 and 2 is found from

$$L_{BR2}(f_k) = L_{BR1}(f_k) + \delta L_{B1}(f_k) - \delta L_{B2}(f_k) \tag{E3}$$

E2.4 This annex provides an approximate method to determine the band-level attenuations $\delta L_B(f_k)$ in Eqs. (E1), (E2), and (E3).

E3 The variables

The variables with their letter symbol, units, and unit symbols are:

a) frequency of the sound f, in hertz; unit symbol Hz;

b) pure-tone attenuation coefficient $\alpha(f)$, in decibels per metre, at frequency f; unit symbol dB/m;

c) pure-tone attenuation $\delta L_t(f_m)$, in decibels, at exact midband frequency f_m over the entire sound propagation path; unit symbol dB;

d) band-level attenuation $\delta L_B(f_k)$, in decibels, over the entire propagation distance s, for a fractional-octave-band filter with nominal midband frequency f_k; unit symbol dB;

e) propagation distance s, in metres, over the entire length of a sound propagation path; unit symbol m; and

f) a relative filter bandwidth B_r equal to the exact filter bandwidth normalized by the exact midband frequency, $B_r = (f_2 - f_1)/f_m$. For base-10 design filters, and in accordance with IEC 1260, $B_r = [10^{3/(20b)} - 10^{-3/(20b)}]$; see Eq. (D3). For one-third-octave-band filters for which the bandwidth designator (1/b) equals 1/3, B_r = 0.23077 to five figures.

E4 The formula

E4.1 The band-level attenuation by atmospheric absorption applicable to a fractional-octave-band sound pressure level by Eqs. (E1) through (E3) is a nonlinear function of the total pure-tone attenuation at the exact midband frequency and over the entire sound-propagation pathlength. The nonlinearity arises from changes to the slope of the sound pressure spectrum during propagation from the source to the receiver over various sound-propagation distances and for various meteorological conditions along the path.

E4.2 According to the approximate method described in this annex, the band-level attenuation $\delta L_B(f_k)$ over sound-propagation distance s equals the product of (1) the total attenuation $\delta L_t(f_m)$ over the same propagation distance for a pure-tone sound at the exact midband frequency f_m and (2) a nonlinear function of this total pure-tone attenuation and the normalized filter bandwidth B_r.

E4.3 The formula for calculating a band-level attenuation through a homogeneous atmosphere is

$$\delta L_B(f_k) = [\delta L_t(f_m)] \times \left\{1 + \left(B_r^2/10\right)[1 - (0.2303)\,\delta L_t(f_m)]\right\}^{1.6} \tag{E4}$$

where pure-tone attenuation over entire pathlength s is found from $\delta L_t(f_m) = [\alpha(f_m)][s]$, and $\alpha(f_m)$ is the pure-tone attenuation coefficient calculated by the method of clause 5 at exact midband frequency f_m for specified meteorological conditions.

NOTES

1 For one-third-octave-band filters, the quantity $(B_r^2/10)$ in Eq. (E4) equals 0 005 3254 to 5 significant figures.

2 The constant of 0 2303 in Eq. (E4) is rounded from $2/[10\ \lg(e^2)]$.

E5 General calculation procedure

For a specified sound-propagation distance and specified average meteorological conditions over the distance, first calculate the pure-tone attenuation coefficient at the exact midband frequency by the method of clause 5. Then, multiply the attenuation coefficient by the propagation distance to determine the pure-tone attenuation $\delta L_t(f_m)$. Substitute the result into Eq. (E4) to determine the band-level attenuation $\delta L_B(f_k)$ for the filter with nominal midband frequency f_k.

E6 Application to stratified atmosphere

E6.1 For propagation over long distances, vertically or along a slanted path, the assumption of a homogeneous atmosphere with constant temperature, moisture content, and pressure may not be realistic. In this case, the atmosphere may be modeled by a stack of N horizontal layers. Calculation of attenuation by atmospheric absorption losses over the pathlength proceeds as follows.

E6.2 Values for air temperature, molar concentration, and atmospheric pressure are specified from measurements or an analytical model at the top and bottom of each of the N layers in the stratified atmosphere. Pure-tone attenuation coefficients $\alpha(f_m)$ are calculated by the method of clause 5 for the meteorological conditions at the top and bottom of each layer and then arithmetically averaged to determine average attenuation coefficients applicable to each layer for each exact midband frequency. The number of layers N should be large enough that the average attenuation coefficient in each layer, at the highest frequency of interest, is representative of the variation of the attenuation coefficient over the thickness of a layer.

E6.3 Pure-tone attenuation over a sound-propagation distance s_n in the n-th layer is obtained from

$$\delta L_{tn}(f_m) = [\alpha_n(f_m)]\,[s_n] \tag{E5}$$

where $\alpha_n(f_m)$ represents the average pure-tone attenuation coefficient at exact midband frequency f_m for the n-th layer; see E6.2.

E6.4 For specified meteorological conditions, the total pure-tone attenuation over the entire sound-propagation pathlength from the source to the receiver (or from the receiver back to the source) is found from a summation of the pure-tone attenuations in the N layers as

$$\delta L_t(f_m) = \sum_{n=1}^{N} \delta L_{tn}(f_m) \tag{E6}$$

E6.5 Total band-level attenuation $\delta L_B(f_k)$ for use in Eqs. (E1), (E2), and (E3) is then computed by the procedure indicated in Eq. (E4) using the total pure-tone attenuation over the entire sound-propagation distance determined according to Eq. (E6).

E7 Application to room acoustics

E7.1 The contribution of atmospheric absorption to the decay of a reverberant broadband sound field in a room may be determined for a fractional-octave-band sound pressure level by combining the expressions given in this annex with those given in clause 8. Referring to Eq. (8), the effective contribution to the total decay rate from atmospheric absorption is given by the $\alpha(f_k)c$ term for the band sound pressure level with nominal midband frequency f_k. This attenuation term may be estimated from the band-level attenuation $\delta L_B(f_k)$ calculated from Eq. (E4).

E7.2 For room acoustics applications, the applicable total sound pathlength may be estimated from the product of the speed of sound c at the average temperature of the air in the room and the reverberation time T for a 60-dB decay. The pure-tone attenuation $\delta L_t(f_m) = [\alpha(f_m)][s]$ over the pathlength [needed to evaluate Eq. (E4)] is calculated from the product of the pure-tone attenuation *coefficient* at exact midband frequency f_m and the effective pathlength given by $s = cT$.

E7.3 For tests of the acoustical properties of materials, where 60-dB reverberation times are measured, the effective value of the $[\alpha(f_k)][c]$ product for broadband sound may be estimated by application of Eq. (E4) to determine a band-level attenuation and then dividing the calculated band-level attenuation $\delta L_B(f_k)$ by the measured 60-dB reverberation time T, in seconds, for that midband frequency.

E7.4 For design applications where the 60-dB reverberation time is to be determined as a function of frequency, iterative calculations of band-level attenuation from Eq. (E4), for various design values for reverberation time T, are required until a stable value, within specified tolerances, is found for the effective contribution of the attenuation, $\alpha(f_k)c$, to the total decay rate, which is also a function of reverberation time.

OTHER ACOUSTICAL STANDARDS AVAILABLE FROM THE STANDARDS SECRETARIAT OF THE ACOUSTICAL SOCIETY OF AMERICA

- **ASA NOISE STDS INDEX 3-1985** Index to Noise Standards

S1 STANDARDS ON ACOUSTICS

- **ANSI S1.1-1994 (ASA 111)** American National Standard Acoustical Terminology
- **ANSI S1.4-1983 (ASA 47)** American National Standard Specification for Sound Level Meters
- **ANSI S1.4A-1985** Amendment to S1.4-1983
- **ANSI S1.6-1984 (R 1990) (ASA 53)** American National Standard Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements
- **ANSI S1.8-1989 (ASA 84)** American National Standard Reference Quantities for Acoustical Levels
- **ANSI S1.10-1966 (R 1986)** American National Standard Method for the Calibration of Microphones
- **ANSI S1.11-1986 (R 1993) (ASA 65)** American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters
- **ANSI S1.12-1967 (R 1986)** American National Standard Specification for Laboratory Standard Microphones
- **ANSI S1.13-1971 (R 1986)** American National Standard Methods for the Measurement of Sound Pressure Levels
- **ANSI S1.20-1988 (R 1993) (ASA 75)** American National Standard Procedures for Calibration of Underwater Electroacoustic Transducers
- **ANSI S1.22-1992 (ASA 100)** American National Standard Scales and Sizes for Frequency Characteristics and Polar Diagrams in Acoustics
- **ANSI S1.25-1991 (ASA 98)** American National Standard Specification for Personal Noise Dosimeters (Revision of ANSI S1.25-1978)
- **ANSI S1.26-1995 (ASA 113)** American National Standard Method for the Calculation of the Absorption of Sound by the Atmosphere
- **ANSI S1.40-1984 (R 1990) (ASA 40)** American National Standard Specification for Acoustical Calibrators
- **ANSI S1.42-1986 (R 1992) (ASA 64)** American National Standard Design Response of Weighting Networks for Acoustical Measurements

S2 STANDARDS ON MECHANICAL VIBRATION AND SHOCK

- **ANSI S2.2-1959 (R 1990)** American National Standard Methods for the Calibration of Shock and Vibration Pickups
- **ANSI S2.3-1964 (R 1990)** American National Standard Specifications for a High-Impact Shock Machine for Electronic Devices
- **ANSI S2.4-1976 (R 1990) (ASA 8)** American National Standard Method for Specifying the Characteristics of Auxiliary Analog Equipment for Shock and Vibration Measurements
- **ANSI S2.5-1962 (R 1990)** American National Standard Recommendations for Specifying the Performance of Vibration Machines
- **ANSI S2.7-1982 (R 1986) (ASA 42)** American National Standard Balancing Terminology
- **ANSI S2.8-1972 (R 1990)** American National Standard for Describing the Characteristics of Resilient Mountings
- **ANSI S2.9-1976 (R 1990) (ASA 6)** American National Standard Nomenclature for Specifying Damping Properties of Materials
- **ANSI S2.10-1971 (R 1990)** American National Standard Methods for Analysis and Presentation of Shock and Vibration Data
- **ANSI S2.11-1969 (R 1986)** American National Standard for the Selection of Calibrations and Tests for Electrical Transducers used for Measuring Shock and Vibration
- **ANSI S2.14-1973 (R 1986)** American National Standard for Specifying the Performance of Shock Machines
- **ANSI S2.15-1972 (R 1986)** American National Standard Specification for the Design, Construction, and Operation of Class HI (High-Impact) Shock-Testing Machine for Lightweight Equipment
- **ANSI S2.17-1980 (R 1986) (ASA 24)** American National Standard Techniques of Machinery Vibration Measurement
- **ANSI S2.19-1989 (ASA 86)** American National Standard Mechanical Vibration–Balance Quality Requirements of Rigid Rotors, Part 1: Determination of Permissible Residual Unbalance
- **ANSI S2.20-1983 (R 1989) (ASA 20)** American National Standard for Estimating Airblast Characteristics for Single Point Explosions in Air, With a Guide to Evaluation of Atmospheric Propagation and Effects
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- **ANSI S2.32-1982 (R 1990) (ASA 32)** American National Standard Methods for the Experimental Determination of Mechanical Mobility. Part II: Measurements Using Single-Point Translation Excitation
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- **ANSI S2.43-1984 (R 1990) (ASA 54)** American National Standard Criteria for Evaluating Flexible Rotor Balance
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- **ANSI S2.46-1989 (ASA 82)** American National Standard Characteristics to be Specified for Seismic Transducers
- **ANSI S2.47-1990 (ASA 95)** American National Standard Vibration of Buildings—Guidelines for the Measurement of Vibrations and Evaluation of Their Effects on Buildings
- **ANSI S2.48-1993 (ASA 108)** American National Standard Servo-Hydraulic Test Equipment for Generating Vibration—Methods of Describing Characteristics
- **ANSI S2.58-1983 (R 1990) (ASA 52)** American National Standard Auxiliary Tables for Vibration Generators—Methods of Describing Equipment Characteristics
- **ANSI S2.60-1987 (ASA 68)** American National Standard Balancing Machines—Enclosures and Other Safety Measures

• **ANSI S2.61-1989 (ASA 78)** American National Standard Guide to the Mechanical Mounting of Accelerometers

• **ANSI Z24.21-1957 (R 1989)** American National Standard Method for Specifying the Characteristics of Shock and Vibration Measurement

S3 STANDARDS ON BIOACOUSTICS

• **ANSI S3.1-1991 (ASA 99)** American National Standard Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms

• **ANSI S3.2-1989 (ASA 85)** American National Standard Method for Measuring the Intelligibility of Speech Over Communication Systems

• **ANSI S3.3-1960 (R 1990)** American National Standard Methods for Measurement of Electroacoustical Characteristics of Hearing Aids

• **ANSI S3.4-1980 (R 1992) (ASA 37)** American National Standard Procedure for the Computation of Loudness of Noise

• **ANSI S3.5-1969 (R 1986)** American National Standard Methods for the Calculation of the Articulation Index

• **ANSI S3.6-1989 (ASA 81)** American National Standard Specification for Audiometers

• **ANSI S3.7-1995 (ASA 112)** American National Standard Method for Coupler Calibration of Earphones

• **ANSI S3.13-1987 (R 1993) (ASA 74)** American National Standard Mechanical Coupler For Measurement of Bone Vibrators

• **ANSI S3.14-1977 (R 1986) (ASA 21)** American National Standard for Rating Noise with Respect to Speech Interference

• **ANSI S3.18-1979 (R 1993) (ASA 38)** American National Standard Guide for the Evaluation of Human Exposure to Whole-Body Vibration

• **ANSI S3.19-1974 (R 1990) (ASA 1)** American National Standard Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs

• **ANSI S3.20-1995 (ASA 114)** American National Standard Psychoacoustical Terminology

• **ANSI S3.21-1978 (R 1992) (ASA 19)** American National Standard Method for Manual Pure-Tone Threshold Audiometry

• **ANSI S3.22-1987 (ASA 70)** American National Standard Specification of Hearing Aid Characteristics

• **ANSI S3.25-1989 (ASA 80)** American National Standard for an Occluded Ear Simulator

• **DRAFT ANSI S3.28-1986 (ASA 66)** Draft American National Standard Methods for the Evaluation of the Potential Effect on Human Hearing of Sounds with Peak A-Weighted Sound Pressure Levels Above 120 Decibels and Peak C-Weighted Sound Pressure Levels Below 140 Decibels

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• **ANSI S3.35-1985 (R 1990) (ASA 59)** American National Standard Method of Measurement of Performance Characteristics of Hearing Aids Under Stimulated *in-situ* Working Conditions

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• **ANSI S3.40-1989 (ASA 79)** American National Standard Guide for the Measurement and Evaluation of Gloves Which are Used to Reduce Exposure to Vibration Transmitted to the Hand

• **ANSI S3.41-1990 (ASA 96)** American National Standard Audible Emergency Evacuation Signal

• **ANSI S3.42-1992 (ASA 103)** American National Standard Testing Hearing Aids with a Broad-Band Noise Signal

• **ANSI S3.43-1992 (ASA 102)** American National Standard Standard Reference Zero for the Calibration of Pure-Tone Bone-Conduction Audiometers

S12 STANDARDS ON NOISE

• **ANSI S12.1-1983 (R 1990) (ASA 49)** American National Standard Guidelines for the Preparation of Standard Procedures for the Determination of Noise Emission from Sources

• **ANSI S12.2-1995 (ASA 115)** American National Standard Criteria for Evaluating Room Noise

• **ANSI S12.3-1985 (R 1990) (ASA 57)** American National Standard Statistical Methods for Determining and Verifying Stated Noise Emission Values of Machinery and Equipment

• **ANSI S12.4-1986 (R 1993) (ASA 63)** American National Standard Method for Assessment of High-Energy Impulsive Sounds with Respect to Residential Communities

• **ANSI S12.5-1985 (R 1990) (ASA 87)** American National Standard Requirements for the Performance and Calibration of Reference Sound Sources

• **ANSI S12.6-1984 (R 1990) (ASA 55)** American National Standard Method for the Measurement of the Real-Ear Attenuation of Hearing Protectors

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• **ANSI S12.9-1993/Part 3 (ASA 109)** American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound, Part 3: Short-Term Measurements with an Observer Present

• **ANSI S12.10-1985 (R 1990) (ASA 61)** American National Standard Methods for the Measurement and Designation of Noise Emitted by Computer and Business Equipment (Revision of ANSI S1.29-1979)

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• **ANSI S12.12-1992 (ASA 104)** American National Standard Engineering Method for the Determination of Sound Power Levels of Noise Sources Using Sound Intensity

• **DRAFT ANSI S12.13-1991 (ASA 97)** Draft American National Standard Evaluating the Effectiveness of Hearing Conservation Programs

- **ANSI S12.14-1992 (ASA 101)** American National Standard Methods for the Field Measurement of the Sound Output of Audible Public Warning Devices Installed at Fixed Locations Outdoors
- **ANSI S12.15-1992 (ASA 106)** American National Standard for Acoustics—Portable Electric Power Tools, Stationary and Fixed Electric Tools, and Gardening Appliances—Measurement of Sound Emitted
- **ANSI S12.16-1992 (ASA 107)** American National Standard Guidelines for the Specification of Noise of New Machinery
- **ANSI S12.18-1994 (ASA 110)** American National Standard Procedures for Outdoor Measurement of Sound Pressure Level
- **ANSI S12.23-1989 (ASA 83)** American National Standard Method for the Designation of Sound Power Emitted by Machinery and Equipment
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- **ANSI S12.40-1990 (ASA 88)** American National Standard Sound Level Descriptors for Determination of Compatible Land Use (Revision of ANSI S3 23-1980)
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