
AMERICAN NATIONAL STANDARD

Methods for Calculation of the Absorption of Sound by the Atmosphere

ANSI/ASA S1.26-2014

Accredited Standards Committee S1, Acoustics

Standards Secretariat
Acoustical Society of America
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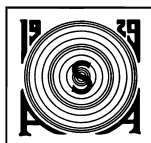
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Foreword

[This Foreword is for information only and is not a part of the American National Standard ANSI/ASA S1.26-2014 American National Standard Methods for Calculation of the Absorption of Sound by the Atmosphere. As such, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the standard.]

This standard comprises a part of a group of definitions, standards, and specifications for use in acoustics. It was developed and approved by Accredited Standards Committee S1 Acoustics, under its approved operating procedures. Those procedures have been accredited by the American National Standards Institute (ANSI). The Scope of Accredited Standards Committee S1 is as follows:

Standards, specifications, methods of measurement and test, and terminology in the field of physical acoustics, including architectural acoustics, electroacoustics, sonics and ultrasonics, and underwater sound, but excluding those aspects which pertain to biological safety, tolerances, and comfort.

This standard is a revision of ANSI S1.26-1995, which has been technically revised. The revision consists of the inclusion of wording explaining that the methods discussed will not necessarily provide similar results and updating of the normative references. 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 has some additional clauses dealing with an approximate method, and includes propagation in large rooms.

This standard contains five informative annexes.

Annex E in this American National Standard is not contained in ISO 9613-1. This annex describes an approximate, non-analytical method to provide 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 propagation in rooms.

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Suggestions for improvements of this standard will be welcomed. They should be sent to Accredited Standards Committee S1, Acoustics, in care of the Standards Secretariat of the Acoustical Society of America, 1305 Walt Whitman Road, Suite 300, Melville, New York 11747. Telephone: +1 (631) 390-0215; FAX: +1 (631) 923-2875; E-mail: asastds@acousticalsociety.org.

American National Standard

Methods 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, using descriptor “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 can be wideband with no significant discrete-frequency components or it may be a combination of wideband and discrete frequency sounds.

NOTE The approximate method will not necessarily give the same results as the primary analytical method.

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 often found in rooms.

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 referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies.

ANSI/ASA S1.11-2014/Part 1 / IEC 61260-1:2014, *American National Standard Electroacoustics - Octave-band and Fractional-octave-band Filters - Part 1: Specifications*

ISO 2533:1975, Standard atmosphere

ISO 2533:1975/Add 1:1985, Hypsometrical tables

ISO 2533:1975/Add 2:1997 Extension to -5000 m and standard atmosphere as a function of altitude in feet

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 can 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

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

where sound pressures p_t and p_i are in pascals, distance s is in meters, α is the pure-tone sound-attenuation coefficient for atmospheric absorption in decibels per meter. From here on, for convenience, the shortened term, attenuation coefficient, will be used for α in place of the full description just given. In Equation (1), the term $\exp(-0.1151 \alpha s)$ 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 meter, not nepers per meter.

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

$$\delta L_t(f) = -10 \lg(p_t^2 / p_i^2) = -10 \lg[\exp(-0.1151 \alpha s)]^2 = \alpha s \quad (2)$$

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

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).

NOTE 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.

NOTE 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

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

and

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

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

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

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

5.2.3 In Equations (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 Equations (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 kilometer for convenience in applications to sound propagation over long pathlengths. Tabular values are presented to three significant figures.

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

5.4.3 Annex A describes a procedure that can 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.

NOTE 1 Frequencies shown in Table 1 are the nominal midband frequencies for one-third-octave-band filters in accordance with ANSI/ASA S1.11/Part 1 / IEC 61260-1. 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

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

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.

NOTE 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 ($p_a = p_r = 101.325 \text{ kPa}$), 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 $+50^\circ\text{C}$);
- atmospheric pressure: less than 200 kPa (i.e., less than two atmospheres); and
- frequency-to-pressure ratio: $4 \times 10^{-4} \text{ Hz/Pa}$ 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 $+50^\circ\text{C}$);
- atmospheric pressure: less than 200 kPa (less than two atmospheres); and
- frequency-to-pressure ratio: $4 \times 10^{-4} \text{ Hz/Pa}$ to 10 Hz/Pa .

6.4 Accuracy of ± 50 percent

Accuracy of the calculated pure-tone attenuation coefficients for atmospheric absorption is estimated to be ± 50 percent 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: $4 \times 10^{-4} \text{ Hz/Pa}$ 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
1,000	1.11	1.43	1.80	2.69	3.74	4.90	6.10	7.25	8.27	9.12	9.74
1,250	1.20	1.52	1.89	2.79	3.87	5.09	6.40	7.72	9.00	10.2	11.2
1,600	1.33	1.65	2.03	2.94	4.04	5.30	6.68	8.13	9.59	11.0	12.3
2,000	1.55	1.87	2.25	3.16	4.27	5.56	6.98	8.52	10.1	11.7	13.3
2,500	1.89	2.21	2.59	3.50	4.62	5.93	7.39	8.98	10.7	12.4	14.2
3,150	2.44	2.76	3.13	4.05	5.17	6.49	7.97	9.60	11.4	13.2	15.1
4,000	3.30	3.62	3.99	4.91	6.04	7.36	8.85	10.5	12.3	14.2	16.2
5,000	4.66	4.98	5.36	6.28	7.40	8.73	10.2	11.9	13.7	15.7	17.7
6,300	6.82	7.14	7.52	8.44	9.57	10.9	12.4	14.1	15.9	17.9	20.0
8,000	10.2	10.6	10.9	11.9	13.0	14.3	15.8	17.5	19.4	21.4	23.5
10,000	15.7	16.0	16.4	17.3	18.4	19.7	21.3	23.0	24.8	26.8	29.0

^{a)} See 5.4.3, Note 1.

(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
1,000	1.65	2.34	3.17	5.11	7.21	9.14	10.6	11.5	11.7	11.6	11.1
1,250	1.74	2.44	3.27	5.28	7.57	9.88	11.9	13.5	14.4	14.8	14.7
1,600	1.88	2.58	3.42	5.48	7.90	10.5	13.0	15.2	16.9	18.0	18.6
2,000	2.10	2.80	3.65	5.73	8.24	11.0	13.9	16.6	19.0	21.0	22.4
2,500	2.44	3.15	4.00	6.10	8.67	11.6	14.7	17.8	20.8	23.5	25.8
3,150	2.99	3.70	4.55	6.66	9.27	12.3	15.5	19.0	22.4	25.7	28.8
4,000	3.86	4.56	5.42	7.54	10.2	13.2	16.6	20.2	24.0	27.8	31.5
5,000	5.24	5.94	6.80	8.93	11.6	14.6	18.1	21.9	25.9	30.0	34.1
6,300	7.42	8.12	8.98	11.1	13.8	16.9	20.4	24.2	28.4	32.7	37.1
8,000	10.9	11.6	12.4	14.6	17.2	20.3	23.9	27.8	32.0	36.5	41.2
10,000	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.

(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
1,000	2.67	4.15	5.87	9.44	12.1	13.2	13.0	12.1	10.9	9.69	8.64
1,250	2.77	4.28	6.07	10.1	13.7	16.0	16.7	16.3	15.3	14.0	12.8
1,600	2.91	4.44	6.28	10.6	14.9	18.4	20.5	21.1	20.7	19.7	18.3
2,000	3.14	4.67	6.54	11.0	15.9	20.5	23.9	26.0	26.7	26.4	25.4
2,500	3.49	5.03	6.92	11.5	16.8	22.2	26.9	30.5	32.7	33.7	33.7
3,150	4.04	5.59	7.49	12.2	17.8	23.7	29.4	34.5	38.4	41.0	42.5
4,000	4.92	6.47	8.38	13.1	18.9	25.2	31.7	37.9	43.4	47.8	51.1
5,000	6.31	7.86	9.78	14.6	20.4	27.1	34.1	41.2	47.9	54.0	59.1
6,300	8.52	10.1	12.0	16.8	22.7	29.6	37.0	44.7	52.4	59.8	66.5
8,000	12.0	13.6	15.5	20.3	26.3	33.2	40.9	49.0	57.4	65.8	73.9
10,000	17.5	19.1	21.0	25.9	31.9	38.9	46.7	55.1	64.0	73.0	82.1

^{a)} See 5.4.3, Note 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	0.465	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
1,000	4.65	7.59	10.6	14.4	14.6	12.9	10.9	9.19	7.82	6.75	5.91
1,250	4.78	7.87	11.3	16.8	18.8	17.9	15.8	13.7	11.8	10.3	9.03
1,600	4.94	8.14	11.8	18.8	23.0	23.6	22.1	19.8	17.5	15.5	13.7
2,000	5.18	8.44	12.3	20.5	26.8	29.7	29.6	27.8	25.4	22.9	20.6
2,500	5.54	8.85	12.8	21.8	30.1	35.6	37.8	37.4	35.5	32.9	30.2
3,150	6.11	9.44	13.5	23.1	32.9	40.9	45.9	47.9	47.5	45.7	43.1
4,000	7.00	10.3	14.5	24.4	35.4	45.5	53.5	58.5	60.7	60.6	59.0
5,000	8.40	11.8	15.9	26.1	37.8	49.6	60.2	68.4	73.9	76.7	77.4
6,300	10.6	14.0	18.2	28.6	40.8	53.8	66.4	77.5	86.4	92.8	96.7
8,000	14.2	17.5	21.7	32.2	44.8	58.6	72.7	86.2	98.2	108	116
10,000	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.