

Annex 1 – Symbols

The symbol definitions used in this book are alphabetically arranged, by type of letter, and tabulated below.

Latin Capitals

A, B, C	scales for sound level measurement
D_e	effective trunk diameter
E	Young's modulus [GPa, Pa or N/m ²]
G	coefficient depending on the geometric characteristics of leaves
I	sound intensity [W/m ²]
L	longitudinal or axial growth direction of a tree
L_a	scattering length
L_s	scattering length
FFT	fast Fourier transform
MOE	modulus of elasticity, also E
N	number of trees per square meter
P_s	ambient pressure [Pa]
R	radial direction related to the annual rings
R_e	effective refraction factor
T	absolute temperature [K]
SPL	sound pressure level [dB]
U	voltage
V	railcar speed [km/h]
V_0	the reference speed [60 km/h]
W	watt
Z	mechanical impedance

Script Latin Lower-case Letters

<i>a</i>	half diameter of elliptical cross area of a trunk
<i>b</i>	half diameter of elliptical cross area of a trunk
r_1	length of the direct ray from the source to the receiver
r_2	the reflected ray
<i>c</i>	sound velocity

d	distance
d_0	reference distance
f	frequency
f'	first maximum frequency
f_{pr}	frequency of the associated pressure minimum
i	$\sqrt{-1}$
k	wave number
l	length
m	mass
n	integer
p	sound pressure
$p_A(t)$	instantaneous sound pressure
p_{rms}	root-mean-square sound pressure [Pa or N/m ²]
$p_{reference}$	reference pressure of 20 μ Pa = 2×10^{-5} N/m ²
r	correlation coefficient
t	time [s]
t_D	growing time of trees [years]
$t_{D_{ref}}$	growing reference-time, trees now aged 12 years
x, y, z	spatial coordinates

Script Latin Capitals

A	excess attenuation
A	acoustic strength
$(Att)_{absorption}$	attenuation produced by leaves absorption
A_d	direct field attenuation
A_s	total scattering attenuation
E_d	energy in the direct field
E_f	energy in the free field
E_r	energy in the reverberant field
$E_{A,T}$	A-weighted sound exposure [Pa ² s]
E_0	reference A-weighted sound exposure [1.15×10^{-10} Pa ² s]
F	total surface of leaves per unit volume
I_a	axial inertia momentum
L_A	sound level on A scale [dB]
$L_{E_{A,T}}$	A-weighted noise exposure [dB]
L_A	A-weighted sound pressure [dB]
$L_{d,n}$	day–night noise level [dB]
L_p	sound pressure level; SPL [dB]
L_{eq}	equivalent continuous sound pressure level [dB]
L_{min}	minimum sound pressure level [dB]
L_{max}	maximum sound pressure level [dB]

L_{10}	sound pressure level exceeded 10% of the time [dB]
L_{50}	sound pressure level exceeded 50% of the time [dB]
L_{90}	sound pressure ambient level [dB]
Q_{res}	quality score
S_d	sound level at distance d
S_0	sound level at the source
T	averaging time
T	long time over which averaging takes place (h)
I	sound source intensity
I_{ref}	sound source reference intensity [10^{-12} W/m ²]
IL or L_I	sound intensity level
P_t	total pressure at the receiver
P_d	direct contribution
P_r	specularly reflected contribution
R_p	pressure reflection coefficient for a plane wave
W	sound power level [dB <i>re</i> W_0]
W_0	the reference sound power [10^{-12} W]
Z	ground impedance

Greek Capitals

Φ	diameter
Δt	difference in time
Δ_L	difference in sound pressure level

Greek Lower-case Letters

α_{leaves}	absorption coefficient of leaves
α_m	absorption coefficient of trees
β	relative admittance
λ	wavelength [m]
π	value of pi = 3.14
ν	frequency [Hz]
θ	ambient temperature [°C]
ρ	density [kg/m ³]
φ	phase angle [°]
σ_e	effective flow resistivity [N s m ⁻⁴]

Annex 2 – Some Theoretical Considerations

The basic equations and theoretical considerations presented in this section can help the reader in a better understanding of sound propagation in air and are based on my discussion with D. Fellot (personal communication).

In an isotropic medium, the equations of propagation of a plane wave are:

$$\frac{\partial^2 p}{\partial t^2} + c^2 \frac{\partial^2 p}{\partial x^2} = 0 \quad (1)$$

and:

$$\frac{\partial^2 v}{\partial t^2} + c^2 \frac{\partial^2 v}{\partial x^2} = 0 \quad (2)$$

where: c is the propagation velocity, p is the sound pressure, v is the particle velocity, t is time and x is the distance of propagation.

In the air, considered as a perfect gas, in which the variations of atmospheric pressure P and volume V are adiabatic, we have $PV^\gamma = \text{constant}$ and the propagation velocity of an acoustic wave at constant temperature can be calculated with the equation:

$$c^2 = \frac{\gamma P}{\rho} \quad \text{and} \quad c = \sqrt{\frac{\gamma P}{\rho}} \quad (3)$$

where γ is the ratio between the specific heat at constant pressure and the specific heat at constant volume and ρ is air density, 1.293 kg/m^3 .

$$\gamma = \frac{C}{c} = 1.4$$

The atmospheric pressure is $P = 1.034 \times 10^5$ Pascal.

From (3), the air velocity has the value $c = \sqrt{1.4 \frac{1.034}{1.293} 10^5} = 334.53 \text{ m/s}$ at a constant temperature of 0°C .

The sound velocity at a temperature T can be deduced from Marriotte's law, written as:

$$PV = nRT \quad (4)$$

where n is the number of moles, $R = 8,314 \text{ J kmol}^{-1} \text{ K}^{-1} = 2 \text{ J}$. V , the volume of the air, is:

$$V = \frac{m}{\rho}, \text{ where } m \text{ is the air mass.}$$

Coming back to (4) we have:

$$P \frac{m}{\rho} = nRT$$

if the temperature is constant, it can be deduced that:

$$\frac{\partial P}{P} - \frac{\partial \rho}{\rho} = 0$$

and:

$$2 \frac{dc}{c} = \gamma \left(\frac{\partial P}{P} - \frac{\partial \rho}{\rho} \right) = 0$$

From previous equations, it can be stated that the sound velocity c is independent of the atmospheric pressure and is strongly dependent on temperature. It can be written as:

$$c^2 = \frac{PV}{m} = \gamma \frac{nRT}{m}$$

the sound velocity c at temperature t [$^{\circ}\text{C}$] is:

$$c = c_0 \sqrt{\left(1 + \frac{t}{273}\right)} \approx c_0 \left(1 + \frac{t}{546}\right)$$

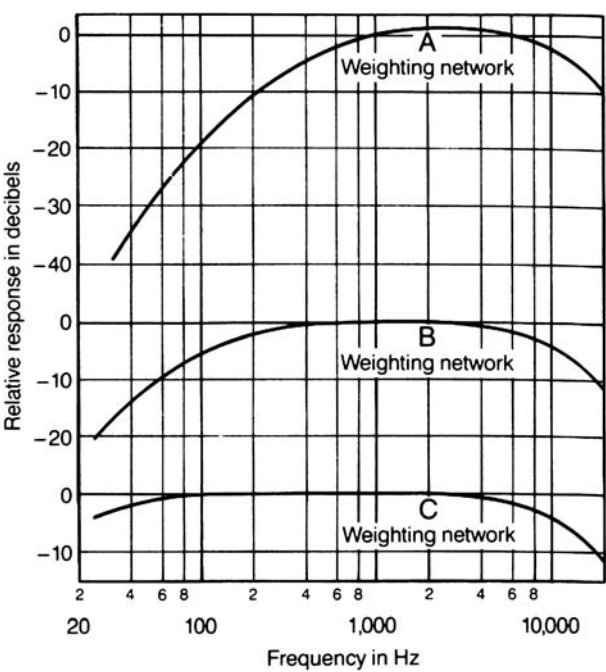
where c_0 is the sound velocity at 0°C .

Because of space limitation, the theoretical aspects treated in this book are limited here.

More theoretical aspects related to the attenuation of sound in air are given by Beranek (1993).

Annex 3 – Frequency Weighting

Frequency weighting is shown in the figure below, which gives the random incidence relative levels as a function of frequency for weighting networks A, B and C (Beranek 1993, p. 808).



Annex 4 – Standards

During the past four decades, the introduction of noise control legislation all over the world required the development of appropriate techniques for the measurement of noise produced by outdoor sources.

The reader interest in more details can refer to *Noise Control Engineering Journal* 1987, vol. 29(1), which is entirely devoted to “Measurement Standards”, to Harris (1998) and to the International Noise Control Engineering (INCE) collected papers.

The standards listed below are placed in four groups as: (a) acoustics – vocabulary, symbols, units, (b) general noise measurement methods, (c) measurement of specific types of sources, (d) measurement of structures used in noise control.

(a) Acoustics – Vocabulary, Symbols, Units

- ANSI S1. 1-1960 (R 1976) Acoustical terminology
- SAE J 1184 Definition of acoustical terms
- ISO R31/7 Quantities and units of acoustics, 2nd edn, 1992-09-01
- ISO 31-2-1992 Quantities and units. Part 2: periodic and related phenomena, corrected and reprinted 1993-05-15
- ISO/TC 12 quantities, units, symbols, conversion factors
- ANSI/ASME, Y10.11-1084 Letter symbols for acoustics

(b) General Noise Measurement Methods

- ANSI S1. 6-1984 Preferred frequencies, frequency levels and band numbers for acoustical measurements
- ANSI S1. 8-1969 (R1974) Preferred reference quantities for acoustical levels

(c) Measurement of Specific Types of Sources

- ANSI S1. 13-1971 (R1986) Methods for measuring sound pressure levels
- ANSI S1. 34-1980 (R1986) Engineering methods for the determination of sound power levels of noise sources for essentially free-field conditions over a reflecting plane

- ANSI S1. 36-1979 (R1985) Survey methods for the determination of sound power levels of noise sources
- ANSI S12. 37-1988 Determination of sound power levels of sound sources. Methods for in situ measurements using a reference sound source
- ASTM E1014-84 Method for the measurement of outdoor A-weighted sound levels
- SAE J 184-1980 Qualifying a sound data acquisition system
- ISO 2204 Acoustics. Guide to international standards on the measurement of airborne acoustical noise and evaluation of its effect on human beings
- ISO 3740 Acoustics. Determination of sound power levels of noise sources. Guidelines for the use of basic standards and for the preparation of noise test codes
- ISO 3744 Acoustics. Determination of sound power levels of noise sources using sound pressure. Engineering method in an essentially free field over a reflecting plane

(d) Measurement of Structures used in Noise Control

- ANSI S12. 36-1987 Methods for the measurement of acoustical performance of outdoor noise barriers
- ASTM E1014 6 1984 Method for the measurement of outdoor A-weighted sound levels
- ISO 1996-1: 2003 Description measurement and assessment of environmental noise. Part 1 Basic quantities and assessment procedures. Part 2 Acquisition of data pertinent to the land use. Part 3 Application to noise limitations
- ISO 9613 Acoustics. Attenuation of sound during propagation outdoors. Part 1 Calculation of the absorption of sound by the atmosphere. Part 2 General methods of calculation
- IEC 804:1985 integrating averaging sound level meters, Amendment 1: 1989, Amendment 2: 1993

Annex 5 – Units

Commonly used units in this book, presented in alphabetic order:

- bel [B]; 1 B is the level of a power quantity when $\log \frac{P}{P_0} = 1$, P_0 being the reference power. Also 1 B is the level of field quantity when $2 \log \frac{A}{A_0} = 1$; 1 B = 1.151293 Np
- decibel [dB]; 10 dB = 1 B; 1 dB = 0.1151293 Np
- degree Celsius [°C]; for conversion to K, use temperature [°C] = T [K] – 273.15
- hertz [Hz]; 1 Hz = s^{-1}
- joule [J]; 1 J = 1 N m = $m^2 kg s^{-2}$
- kilogram [kg]; derived unit kg/m^3
- kelvin [K]
- meter [m]; derived unit m^2 , m^3 m/s, m/s^2
- neper [Np]; 1 Np is the level of a field quantities when the logarithm of the ratio of two amplitude is 1 as $\ln \frac{A}{A_0} = 1$
- newton [N]; 1 N = $1 kg m s^{-2}$
- octave – the frequency interval between f_1 and f_2 , if $\frac{f_1}{f_2} = 2$
- pascal [Pa]; 1 Pa = $1 N m^{-2} = m^{-1} kg s^{-2}$
- phone [phone]; 1 phone is the loudness level when $2 \log \frac{p_{eff}}{p_0} = 0.1$. For a pure tone of frequency 1 kHz, 1 phone \approx 1 dB
- radian [rad]; 1 rad = mm^{-1} ; $1^\circ = \frac{\pi}{180}$ rad, derived unit rad/s
- second [s]
- watt [W]; 1 W = $1 J s^{-1} = m^2 kg s^{-3}$

The reader interested in measures, units and conversions is invited to visit:

<http://www.ex.ac.uk/cimt/dictunit/dictunit.htm> (a dictionary of units by F. Tapson)

<http://physics.nist.gov/cuu/units> (the NIST reference on constants, units and uncertainty)

<http://convert-me.com/en> (online conversion of weights and units, metric conversions)

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