University of New Hampshire

ADEON Project Dictionary (Terminology Standard)
FINAL

Atlantic Deepwater Ecosystem Observatory Network (ADEON): An Integrated System for Long-Term Monitoring of Ecological and Human Factors on the Outer Continental Shelf

Contract: M16PC00003

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Project Dictionary

Terminology Standard

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Contents

Figures

Tables

Abbreviations

Acoustical and non-acoustical abbreviations are listed in Tables 1 and 2, respectively.

Table 1. Acoustical abbreviations.

Abbreviation	Meaning
AAF	Anti-alias filter
ABC	area backscattering coefficient
ABS	area backscattering strength
ADC	analog to digital converter
ASASSL	areic surface-affected source spectral density level
ASSL	areic source spectral density level
AZFP	Acoustic Zooplankton Fish Profiler (ASL Environmental Sciences)
DFT	discrete Fourier transform
DR	dynamic range
ESDL	sound exposure spectral density level
ESSL	energy source spectral density level
FSR	full-scale input range
IMD	intermodulation distortion
Lpk	zero-to-peak sound pressure level (synonym of peak sound pressure level)
Lrms	root-mean-square sound pressure level (synonym of sound pressure level – see also SPL)
PL	propagation loss
PSDL	mean-square sound pressure spectral density level
ROC	receiver operating characteristic (curve)
SAESSL	surface-affected energy source spectral density level
SASSL	surface-affected source spectral density level
SEL	sound exposure level
SELw	weighted sound exposure level
SL	source level
SNR	Signal-to-noise ratio (power ratio)
SPL	sound pressure level (synonym of root-mean-square sound pressure level – see also Lrms)
SSL	source spectral density level
SWL	sound power level
THD	total harmonic distortion
TL	transmission loss
VBC	volume backscattering coefficient
VBS	volume backscattering strength

Table 2. Non-acoustical abbreviations.

Abbreviation	Meaning
ADEON	Atlantic Deepwater Ecosystem Observatory Network
AIS	Automatic Identification System (for shipping)
AM	arithmetic mean
ANSI	American National Standards Institute
BIPM	International Bureau of Weights and Measures
BOEM	Bureau of Ocean Energy Management
cdf	cumulative distribution function
DFT	discrete Fourier transform
EC	European Commission
ESA	Endangered Species Act
EU	European Union
GES	(MSFD) Good Environmental Status
GM	geometric mean
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IQOE	International Quiet Ocean Experiment
ISO	International Organization for Standardization
ISQ	International System of Quantities
IWC	International Whaling Commission
JASCO	JASCO Applied Sciences
JIP	E&P Sound and Marine Life Joint Industry Programme
JIP UA-R	JIP reporting standard (Ainslie and de Jong 2018)
JIP UA-T	JIP terminology standard (Ainslie et al. 2018c)
JOMOPANS	Joint Monitoring Programme for Ambient Noise North Sea
LSB	least significant bit
MMPA	Marine Mammal Protection Act
MS	(EU) Member State
MSFD	(EU) Marine Strategy Framework Directive
NA	not applicable
NMFS	NOAA National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OASIS	Ocean Acoustical Services and Instrumentation Systems, Inc.
OCS	outer continental shelf
ONR	Office of Naval Research
ONR-G	ONR Global
PI	Principal Investigator
rms	root-mean-square (square root of the mean-square value)

rss	root-sum-square (square root of the summed squared value)
SBU	Stony Brook University
SFA	Sustainable Fisheries Act
SI	International System of Units
SWFSC	NOAA Southwest Fisheries Science Center
TNO	Netherlands Organisation for Applied Scientific Research
UNH	University of New Hampshire
UTC	Coordinated Universal Time

1. Introduction

1.1. ADEON Project

The Atlantic Deepwater Ecosystem Observatory Network (ADEON) for the US Mid- and South Atlantic Outer Continental Shelf (OCS) has been developed and was deployed in fall 2017. The lead principal investigator (PI) for this project is Dr. Jennifer Miksis-Olds, University of New Hampshire (UNH). Dr. Miksis-Olds leads a collaborative research team consisting of individuals from Applied Ocean Sciences, UNH, JASCO, Stony Brook University, Florida Atlantic University, NOAA's Southwest Fisheries Science Center, OASIS, and TNO.

This observatory network is generating multi-year measurements of the natural and human factors active in this region, thus informing the ecology and soundscape of the OCS. Long-term observations of living marine resources and marine sound will assist federal agencies, including the Bureau of Ocean Energy Management (BOEM), the Office of Naval Research (ONR), and the National Oceanic and Atmospheric Administration (NOAA), in complying with mandates in the Endangered Species Act (ESA), Marine Mammal Protection Act (MMPA), and Sustainable Fisheries Act (SFA).

1.2. Objectives

1.2.1. ADEON Project Objectives

The ADEON project objectives are to:

- Establish an ecosystem observation network that provides baseline monitoring and supports predictive modeling of the soundscape and its relationship to marine life and the environment of the Mid- and South Atlantic Planning Areas.
- Develop standardized measurement and processing methods and visualization metrics for comparing ADEON observations with data from other monitoring networks.
- Assess baseline soundscape and ecosystem conditions in support of predictive environmental modeling and trend analyses in the planning areas.
    - How do soundscape and ecosystem components vary with water depth across the OCS?
    - How do the soundscape and ecosystem components vary with latitude along the OCS?
    - Where are the hot spots of human activity for consideration in ecosystem/habitat health impacts?
- Assess the spatial and temporal distribution of the soundscape and biological scatterers, including their expected variation and correlation with distance from the lander locations.
    - What are the environmental factors that define and constrain the horizontal range of appropriate extrapolation of observations measured at the stationary lander sites?
- Develop and apply new methods for the effective visualization of five-dimensional (5-D–time, latitude, longitude, frequency, and depth) soundscape data with interactive visual analysis tools that enable users to explore, analyze, and integrate ancillary ecosystem data streams with the 5-D soundscape.
- Develop a robust data management system that archives and provides public access to multiple data streams to encourage future development of ecological models targeted at questions beyond the scope of this study.

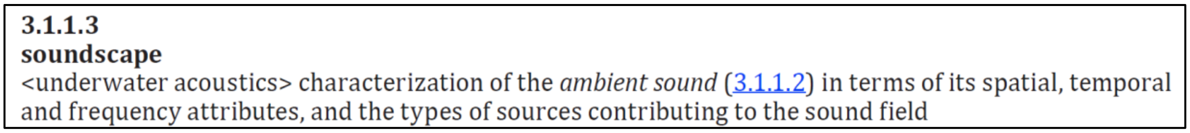
1.2.2. ADEON Standardization Objectives

The objectives of ADEON's Standardization task are to:

- Ensure compatibility within ADEON between soundscapes based on measurements and those based on models;
- Ensure compatibility between measurements made by different researchers and institutes within ADEON;
- Facilitate compatibility between ADEON soundscapes, whether based on measurement or model prediction, and soundscapes produced by a hypothetical future or parallel project within the US Exclusive Economic Zone (EEZ);
- Facilitate compatibility between metrics used to quantify ADEON soundscapes and those used to monitor ambient sound in the context of the EU's Marine Strategy Framework Directive (MSFD).

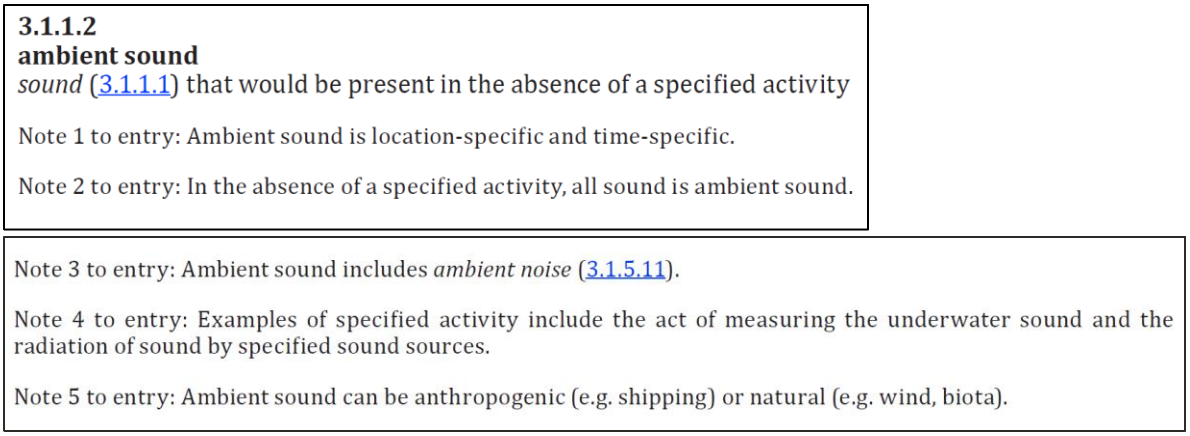
1.3. What is a Soundscape?

For airborne acoustics, in the context of human hearing, the term "soundscape" usually implies an element of perception of the sound. For example, entry 2.3 of the International Organization for Standardization (ISO 2014) defines a soundscape as an "acoustic environment as perceived or experienced and/or understood by a person or people, in context". However, the same term is used without this implication in contexts other than human hearing, both in air (Farina et al. 2011, Pijanowski et al. 2011, Gage and Axel 2014) and in water (Fay 2009, Dugan et al. 2013, Hastings and Širović 2015). For this reason, the definition of "soundscape" according to the international underwater acoustical terminology standard ISO (2017) also excludes a perception element. Following ISO (2017), ADEON therefore defines the terms "soundscape" and "ambient sound" as shown in Figures 1 and 2, respectively. The related terms "auditory scene" and "auditory stream" are in use to describe the perception of a soundscape by a listener (Hulse 2002, Shamma et al. 2011).



3.1.1.3
soundscape
<underwater acoustics> characterization of the *ambient sound* (3.1.1.2) in terms of its spatial, temporal and frequency attributes, and the types of sources contributing to the sound field

Figure 1. Definition of "soundscape" from ISO (2017).



3.1.1.2
ambient sound
sound (3.1.1.1) that would be present in the absence of a specified activity

Note 1 to entry: Ambient sound is location-specific and time-specific.

Note 2 to entry: In the absence of a specified activity, all sound is ambient sound.

Note 3 to entry: Ambient sound includes *ambient noise* (3.1.5.11).

Note 4 to entry: Examples of specified activity include the act of measuring the underwater sound and the radiation of sound by specified sound sources.

Note 5 to entry: Ambient sound can be anthropogenic (e.g. shipping) or natural (e.g. wind, biota).

Figure 2. Definition of "ambient sound" from ISO (2017).

1.4. Use of Standardized Terminology

The terminology standard ISO 18405:2017 ‘Underwater Acoustics – Terminology’ (ISO 2017) has international consensus and was developed specifically for underwater acoustics. The main alternative to ISO (2017) was ANSI S1.1-2013 ‘Acoustical Terminology’ (ANSI S1.1-2013 2013). ANSI S1.1 contains bioacoustical terminology for human hearing in air (for example, by default sound exposure level as defined by ANSI (2013) is A-weighted) and for biological contributions to sonar noise and reverberation. However, bioacoustical terminology relevant to aquatic animals and to underwater soundscapes is outside the scope of ANSI (2013), making ISO (2017) a natural choice for ADEON. ISO (2017) has been adopted by the ADEON project and is followed throughout this report.

Every attempt has been made by the ADEON project to follow relevant international standards. Nevertheless, where there is a project-specific need to depart from an international standard, this is achieved by giving the ADEON standard precedence over all others. For acoustical terminology, the following standards are followed, in order of decreasing precedence:

- Project Dictionary (Terminology Standard) (this document)
- ISO 18405:2017 Underwater Acoustics – Terminology (ISO 2017)
- ISO 80000-8:2020 Quantities and Units – Acoustics (ISO 2020)
- ISO 80000-3:2019 Quantities and Units – Space and Time (ISO 2019)
- ISO 80000-1:2009 Quantities and Units – General (ISO 2009)
- IEC 60027-3:2002 Letter symbols to be used in electrical technology – Part 3: Logarithmic and related quantities, and their units (IEC 2002)

The words “shall” and “should” are used throughout this report to indicate requirements and recommendations, respectively.

1.5. Purpose of This Report

The purpose of this report is to provide terminology for the ADEON project. The project’s focus on soundscapes means that the main focus of this report is on acoustical terminology relevant to soundscapes.

This report was published in draft form in 2017 (Ainslie et al. 2017). The 2017 draft was largely followed by the North Sea ambient sound monitoring project JOMOPANS in developing its terminology standard (Wang and Robinson 2020).

1.6. Report Structure

The remainder of this report is structured as follows:

- Section 2 introduces mathematical symbols and conventions used throughout the report.
- Section 3 defines general acoustical terminology, followed by specialized acoustical terminology for soundscape description (Section 4) and hardware (Section 5). It is customary in underwater acoustics to convert acoustic quantities such as sound pressure or sound exposure to levels in decibels, and these conversions are specified in Section 6.
- Section 7 specifies requirements for reporting soundscapes.
- Finally, Appendix A defines non-acoustical terminology such as units of distance and time, and data processing levels used by ADEON.

2. Mathematical Symbols and Conventions

For mathematical symbols generally, ISO (2009) shall be followed. Functions and operations of particular relevance include logarithms and Fourier transforms.

2.1. Logarithms

Symbols for natural, base 2 and base 10 logarithms are listed in Table 3.

Table 3. Standard symbols for logarithms (ISO 2009).

Type of logarithm	Symbol	Alternative symbol	Notes
base 2	$\log_2 x$	lb x	
base e	$\log_\mathrm{e} x$	ln x	Also known as natural logarithm
base 10	$\log_{10} x$	lg x	

2.2. Fourier Transform

As a general rule, a lower case symbol is used for a time domain quantity such as sound pressure, $p(t)$, or source waveform, $s(t)$, with the upper case symbols $P(f)$ and $S(f)$ for the corresponding Fourier transforms (ISO 2019). Specifically, if $x(t)$ and $X(f)$ form a Fourier transform pair, they are related by:

$$X(f) = \int_{-\infty}^{+\infty} x(t) \exp(-2\pi \mathrm{i} f t)\, \mathrm{d}t$$

$$x(t) = \int_{-\infty}^{+\infty} X(f) \exp(+2\pi \mathrm{i} f t)\, \mathrm{d}f \,.$$

2.3. Discrete Fourier Transform

Modern digital acquisition systems use a discrete representation of the Fourier transform known as a discrete Fourier transform (DFT). A DFT is indicated in the following equations by attaching an integer index m to the frequency variable, $X(f_m)$, such that the DFT pair corresponding to the continuous variables $X(f)$ and $x(t)$ are (Ainslie et al. 2018c):

$$X(f_m) = \delta t \sum_{n=0}^{M-1} x(t_n) \exp(-2\pi \mathrm{i}\ nm/M)$$

$$x(t_n) = \frac{1}{M\delta t} \sum_{m=0}^{M-1} X(f_m) \exp(+2\pi \mathrm{i}\ nm/M)\,,$$

where M is the number of sample points. In mathematical treatments of the DFT, the factor δt is sometimes omitted (see p 19 of Ainslie et al. 2018c).

3. General Acoustical Terminology

General acoustical terminology is defined in Table 4 (concepts), Table 5 (frequency bands), and Table 6 (basic sound field properties).

Table 4. General acoustical terminology: Concepts.

Term	Definition
sound	alteration in pressure, stress or material displacement propagated via the action of elastic stresses in an elastic medium and that involves local compression and expansion of the medium, or the superposition of such propagated alterations **NOTES**: Source: ISO (2017), entry 3.1.1.1 If only acoustic pressure fluctuations are present (implying the absence of mean flow and turbulence), the total pressure at a location is the background hydrostatic pressure plus the sound pressure.
ambient sound	*sound* that would be present in the absence of a specified activity **NOTES**: See Figure 2 Source: ISO (2017), entry 3.1.1.2
soundscape	*In underwater acoustics,* characterization of the ambient sound in terms of its spatial, temporal and frequency attributes, and the types of sources contributing to the sound field **NOTES**: See Figure 1 Source: ISO (2017), entry 3.1.1.3
material element	smallest element of the medium that represents the medium's mean density **NOTES**: Source: ISO (2017), entry 3.1.1.5
signal	specified time-varying electric current, voltage, sound pressure, sound particle displacement, or other field quantity of interest **NOTES**: Source: ISO (2017), entry 3.1.5.8
acoustic self-noise	sound at a receiver caused by the deployment, operation, or recovery of a specified receiver, and its associated platform **NOTES**: Source: ISO (2017), entry 3.1.5.10
ambient noise	sound except acoustic self-noise and except sound associated with a specified signal **NOTES**: Source: ISO (2017), entry 3.1.5.11
temporal observation window	interval of time within which a statistic of the sound field is calculated or estimated **NOTES**: Examples of statistic include rms sound pressure, peak sound pressure, and sound pressure kurtosis. An example is rms sound pressure calculated using a temporal observation window of 1 min.

temporal analysis window	interval of time during which statistics are calculated over multiple temporal observation windows **NOTES**: An example is a 24 h distribution of rms sound pressure calculated using a temporal observation window of 1 min. In this example, the temporal analysis window is 24 h and the temporal observation window is 1 min.
spatial observation window	region of space within which a spatially averaged power quantity is calculated or estimated, for a specified duration of the temporal observation window **NOTES**: The size of a spatial observation window is specified by means of an area (e.g., 1000 km^2) and a depth range (e.g., 50 to 200 m). The power quantity can be the mean-square sound pressure.
spatial analysis window	region of space within which statistics are calculated over multiple spatial observation windows **NOTES**: The size of a spatial analysis window is specified by means of an area (e.g., 100 000 km^2) and a depth range (e.g., 50 to 200 m).

Table 5. General acoustical terminology: Units of logarithmic quantities.

Term	Definition
octave **symbol**: oct	logarithmic frequency range between frequencies f_1 and f_2 when f_2/f_1 = 2 **NOTES**: Based on ISO (2020). 1 oct = (lg2) dec ≈ 0.3010 dec
decade **symbol**: dec	logarithmic frequency interval between frequencies f_1 and f_2 when f_2/f_1 = 10 **NOTES**: Based on ISO (2007). 1 dec = (lb 10) oct ≈ 3.322 oct Standard decade bands adopted by ADEON are specified in Table 6 of Ainslie et al. (2018b).
one-third octave **synonym**: one-third octave (base 2) **symbol**: oct	one third of an octave **NOTES**: From ISO (2017), entry 3.1.4.1. One one-third octave is approximately equal to a decidecade: 1/3 oct ≈ 1.003 ddec
decidecade **synonym**: one-third octave (base 10) **symbol**: ddec	one tenth of a decade **NOTES**: From ISO (2017), entry 3.1.4.2. One decidecade is approximately equal to one third of an octave: 1 ddec ≈ 0.3322 oct. International standard decidecade bands adopted by ADEON are listed in Table 5 of Ainslie et al. (2018b).
millidecade **synonym**: savart **symbol**: mdec	one thousandth of a decade **NOTES**: One millidecade is one hundredth of a decidecade.
decibel **symbol**: dB	difference in level between two power quantities P_1 and P_2 when $P_2/P_1 = 10^{0.1}$ **NOTES**: The two power quantities shall be of the same kind. The symbol dB is reserved for decibel (not decibyte). The symbol B is reserved for byte (not bel).

Table 6. General acoustical terminology: Basic sound field properties.

Term	Definition
sound pressure **symbol**: $p(t)$ **unit**: Pa	contribution to total pressure caused by the action of sound **NOTES**: Source: ISO (2017), entry 3.1.2.1
sound pressure spectrum **synonym**: complex sound pressure spectrum **symbol**: $P(f)$ **unit**: Pa/Hz	Fourier transform of the sound pressure **NOTES**: Source: ISO (2017), entry 3.1.2.2
sound particle displacement **symbol**: $\delta(t)$ **unit**: m	displacement of a material element caused by the action of sound **NOTES**: Source: ISO (2017), entry 3.1.2.9
sound particle velocity **symbol**: $u(t)$ **unit**: m/s	contribution to velocity of a material element caused by the action of sound **NOTES**: Source: ISO (2017), entry 3.1.2.10
sound particle acceleration **symbol**: $a(t)$ **unit**: m/s^2	contribution to acceleration of a material element caused by the action of sound **NOTES**: Source: ISO (2017), entry 3.1.2.11

4. Acoustical Terminology for Soundscape Description

Qualitative descriptions of concepts like “sound” and “soundscape” are needed (see Table 4) before the physical characteristics of these concepts (Table 7) and properties of sound sources (Table 8) and characteristics of propagation and scattering (Table 9) can be quantified.

Table 7. Sound field metrics (see Section 6 for definitions of logarithmic quantities such as levels and level differences).

Preferred term	Definition
zero-to-peak sound pressure **synonym**: peak sound pressure; peak amplitude **symbol**: $p_{0-\mathrm{pk}}$; p_{pk} **unit**: Pa	greatest magnitude of the sound pressure during a specified time interval, for a specified frequency range **NOTES**: Source: ISO (2017), entry 3.1.2.3
mean-square sound pressure **symbol**: $\overline{p^2}$ **unit**: Pa^2	integral over a specified time interval of squared sound pressure, divided by the duration of the time interval, for a specified frequency range **NOTES**: Source: ISO (2017), entry 3.1.3.1
time-integrated squared sound pressure **synonym**: sound pressure exposure **abbreviation**: sound exposure **symbol**: $E_{p,T}$ **unit**: Pa^2 s	*In underwater acoustics,* integral of the square of the sound pressure, p, over a specified time interval or event, for a specified frequency range **NOTES**: Source: ISO (2017), entry 3.1.3.5
sound pressure exposure spectral density **synonym**: sound exposure spectral density **symbol**: $E_{f,T}$ **unit**: Pa^2 s/Hz	*In underwater acoustics,* distribution as a function of non-negative frequency of the time-integrated squared *sound pressure* per unit bandwidth of a sound having a continuous spectrum **NOTES**: Source: ISO (2017), entry 3.1.3.9
mean-square sound pressure spectral density **symbol**: $\left(\overline{p^2}\right)_f$ **unit**: Pa^2/Hz	distribution as a function of non-negative frequency of the mean-square sound pressure per unit bandwidth of a sound having a continuous spectrum **NOTES**: Source: ISO (2017), entry 3.1.3.13
average mean-square sound pressure **symbol**: $\langle\overline{p^2}\rangle$ **unit**: Pa^2	integral over a specified spatial volume of mean-square sound pressure, divided by that volume
sound pressure kurtosis **symbol**: β **unit**: 1	kurtosis of the sound pressure, $p(t)$, over a specified time interval, t_1 to t_2, for a specified frequency range **NOTES**: Source: ISO (2017), entry 3.1.5.5

Table 8. Source properties. Modifications to ISO (2017) are shown in blue text.

Preferred term	Definition
acoustic far field	spatial region in a uniform medium where the direct-path field amplitude, compensated for absorption loss, varies inversely with range **NOTES**: Source: ISO (2017), entry 3.3.1.1
far-field sound pressure	sound pressure in the acoustic far field of a sound source **NOTES**: Source: ISO (2017), entry 3.3.1.2
acoustic center	point from which outgoing wavefronts appear to diverge in the acoustic far field, under free-field conditions **NOTES**: Source: ISO (2017), entry 3.3.1.3
source waveform **symbol**: s **unit**: Pa m	product of distance in a specified direction, r, from the acoustic center of a sound source and the delayed far-field sound pressure, $p(t - t_0 + r/c)$, for a specified time origin, t_0, if placed in a hypothetical infinite uniform lossless medium of the same density and sound speed, c, as the actual medium at the location of the source, with identical motion of all acoustically active surfaces as the true source in the true medium, where t is time **NOTES**: Based on ISO (2017), entry 3.3.1.4.
source spectrum **symbol**: S **unit**: Pa m/Hz	Fourier transform of the source waveform **NOTES**: Source: ISO (2017), entry 3.3.1.8
source factor **symbol**: F_S **unit**: Pa^2 m^2	product of the square of the distance from the acoustic center of a sound source, in a specified direction, r^2, and mean-square sound pressure in the acoustic far field at that distance, $\overline{p^2}$, of a sound source, if placed in a hypothetical infinite uniform lossless medium of the same density and sound speed as the real medium at the location of the source, with identical motion of all acoustically active surfaces as the true source in the true medium **NOTES**: Based on ISO (2017), entry 3.3.1.6.
energy source factor **symbol**: $F_{\mathrm{S},E}$ **unit**: Pa^2 m^2 s	product of the square of the distance from the acoustic center of a sound source, in a specified direction, r^2, and time-integrated squared sound pressure in the acoustic far field at that distance, $E_p(r)$, of a sound source, if placed in a hypothetical infinite uniform lossless medium of the same density and sound speed as the real medium at the location of the source, with identical motion of all acoustically active surfaces as the true source in the true medium **NOTES**: Based on ISO (2017), entry 3.3.1.5.
source factor spectral density **symbol**: $F_{\mathrm{S},f}$ **unit**: Pa^2 m^2/Hz	distribution as a function of non-negative frequency of the source factor per unit bandwidth of a source having a continuous spectrum
energy source factor spectral density **symbol**: $F_{\mathrm{S},E,f}$ **unit**: Pa^2 m^2 s/Hz	distribution as a function of non-negative frequency of the energy source factor per unit bandwidth of a source having a continuous spectrum

surface-affected source waveform **symbol**: s' **unit**: Pa m	product of distance in a specified direction, r, from the acoustic center of a sound source and its sea surface-reflected image and the delayed far-field sound pressure, $p(t - t_0 + r/c)$, for a specified time origin, t_0, if placed in a hypothetical semi-infinite uniform lossless medium of the same density and sound speed, c, as the actual medium at the location of the source, with identical motion of all acoustically active surfaces as the true source in the true medium, where t is time **NOTES**: Based on ISO (2017), entry 3.3.1.7.
surface-affected source spectrum **symbol**: S' **unit**: Pa m/Hz	Fourier transform of the surface-affected source waveform **NOTES**: Source: ISO (2017), entry 3.3.1.9
surface-affected source factor **symbol**: $F_{\mathrm{S}}{}'$ **unit**: Pa^2 m^2	product of the square of the distance from the acoustic center of a sound source and its sea surface-reflected image, in a specified direction, r^2, and mean-square sound pressure in the acoustic far field at that distance, $\overline{p^2}$, of a sound source, if placed in a hypothetical semi-infinite uniform lossless medium of the same density and sound speed as the real medium at the location of the source, with identical motion of all acoustically active surfaces as the true source in the true medium **NOTES**: Needed for the specification of wind source level
surface-affected energy source factor **symbol**: $F'_{\mathrm{S},E}$ **unit**: Pa^2 m^2 s	product of the square of the distance from the acoustic center of a sound source and its sea surface-reflected image, in a specified direction, r^2, and time-integrated squared sound pressure in the acoustic far field at that distance, $E_p(r)$, of a sound source, if placed in a hypothetical semi-infinite uniform lossless medium of the same density and sound speed as the real medium at the location of the source, with identical motion of all acoustically active surfaces as the true source in the true medium
surface-affected source factor spectral density **symbol**: $F'_{\mathrm{S},f}$ **unit**: Pa^2 m^2/Hz	distribution as a function of non-negative frequency of the surface-affected source factor per unit bandwidth of a source having a continuous spectrum
surface-affected energy source factor spectral density **symbol**: $F'_{\mathrm{S},E,f}$ **unit**: Pa^2 m^2 s/Hz	distribution as a function of non-negative frequency of the surface-affected energy source factor per unit bandwidth of a source having a continuous spectrum
areic source factor spectral density **symbol**: $F_{\mathrm{S},f,A}$ **unit**: Pa^2 m^2 Hz^{-1}/m^2	quotient of source factor spectral density from a specified region of the surface and the area of that specified region **NOTES**: An alternative way to write the unit of the quantity is Pa^2 Hz^{-1}. However, the full form Pa^2 m^2 Hz^{-1}/m^2 is preferred to avoid the risk of confusion with the unit for mean-square sound pressure spectral density.
areic surface-affected source factor spectral density **symbol**: $F'_{\mathrm{S},f,A}$ **unit**: Pa^2 m^2 Hz^{-1}/m^2	quotient of surface-affected source factor spectral density from a specified region of the surface, evaluated in the vertical direction, and the area of that specified region **NOTES**: An alternative way to write the unit of the quantity is Pa^2 Hz^{-1}. However, the full form Pa^2 m^2 Hz^{-1}/m^2 is preferred to avoid the risk of confusion with the unit for mean-square sound pressure spectral density.

Table 9. Propagation and scattering metrics.

Preferred term	**Definition**
propagation factor	mean-square sound pressure divided by the source factor in a specified direction **NOTES**: From ISO (2017), entry 3.4.1.1
volume differential scattering cross section per unit volume **symbol**: σ_v **unit:** $\mathrm{m}^2\ \mathrm{sr}^{-1}/\mathrm{m}^3$	quotient of the ensemble-average of the free-field time-averaged sound power radiated per unit solid angle in a specified direction in the far field of the scattered field per unit volume of water by the time-averaged sound intensity of the incident field, for an incident plane wave **NOTES**: From ISO (2017), entry 3.4.2.5 The volume differential scattering cross section per unit volume is related to the volume scattering strength (S_v) according to $\sigma_\mathrm{v} = \sigma_{\mathrm{v},0} 10^{S_\mathrm{v}/(10\ \mathrm{dB})}$ where $\sigma_{\mathrm{v},0}$ is the reference value: $\sigma_{\mathrm{v},0} = 1\ \mathrm{m}^2\ \mathrm{sr}^{-1}/\mathrm{m}^3$
volume backscattering coefficient **abbreviation**: VBC **symbol**: $s_{\mathrm{v,bs}}$ **unit:** $\mathrm{m}^2\ \mathrm{sr}^{-1}/\mathrm{m}^3$	volume differential scattering cross section per unit volume evaluated in the backscattering direction **NOTES**: The volume backscattering coefficient is related to the volume backscattering strength ($S_{\mathrm{v,bs}}$) according to $s_{\mathrm{v,bs}} = \sigma_{\mathrm{v},0} 10^{S_{\mathrm{v,bs}}/(10\ \mathrm{dB})}$ where $\sigma_{\mathrm{v},0}$ is the reference value: $\sigma_{\mathrm{v},0} = 1\ \mathrm{m}^2\ \mathrm{sr}^{-1}/\mathrm{m}^3$ Based on MacLennan et al. (2002). The subscript ‘bs’ may be omitted if no ambiguity results from doing so. The backscattering direction is aligned with the vector from scatterer to source.
area backscattering coefficient **abbreviation**: ABC **symbol**: s_a **unit:** $\mathrm{m}^2\ \mathrm{sr}^{-1}/\mathrm{m}^2$	the quantity $s_\mathrm{a} = \int_{z_1}^{z_2} s_{\mathrm{v,bs}}\,\mathrm{d}z$ where $s_{\mathrm{v,bs}}$ is the volume backscattering coefficient for a specified frequency and direction of the incident plane wave and the integral is over depth z from a specified minimum value ($z = z_1$) to a specified maximum value ($z = z_2$) **NOTES**: The area backscattering coefficient is related to the area backscattering strength (S_a) according to $s_\mathrm{a} = \sigma_{\mathrm{a},0} 10^{S_\mathrm{a}/(10\ \mathrm{dB})}$ where $\sigma_{\mathrm{a},0}$ is the reference value: $\sigma_{\mathrm{a},0} = 1\ \mathrm{m}^2\ \mathrm{sr}^{-1}/\mathrm{m}^2.$ The area backscattering coefficient is a property of the sea volume. Though it shares the same units, it differs from the surface backscattering coefficient, which is a property of the sea surface. The area backscattering coefficient is a measure of the areic density of scattering matter within the specified minimum and maximum depths of integration. If the volume backscattering coefficient is isotropic the area backscattering coefficient is independent of direction.

5. Acoustical Terminology for Hardware

This section describes the terminology needed for the ADEON hardware specification (Martin et al. 2018). The description includes a list of concepts (Table 10), followed by a sequence of tables listing the terminology used for characterizing the properties of a hydrophone (Table 11), a pre-amplifier and an anti-alias filter (AAF) (Table 12), a passive acoustic recorder system (comprising one hydrophone, one pre-amplifier, one AAF, and one analog to digital converter (ADC); Table 13), and the terminology related to active acoustic echo sounders (Table 14).

Table 10. Acoustical terminology for ADEON hardware specification: Concepts.

Term	Definition
hydrophone	transducer designed to convert underwater sound to electricity **NOTES**: hydrophone input = system input
hydrophone input **synonym**: system input	pressure fluctuation in the water at the sensitive face of the hydrophone
pre-amplifier	electronic component that increases the amplitude of an electric charge, current, or voltage
Nyquist frequency	half the sampling rate of a digital acquisition system
anti-alias filter (AAF)	low-pass filter used to avoid undersampling an analog signal during digitization by removing frequencies above the Nyquist frequency of the analog-to-digital converter
analog-to-digital converter (ADC)	electronic component that samples an analog electric input (signal plus noise) into a digitized representation of that electric input **NOTES**: The electric input is usually a voltage. Compare IEEE (STD-1241-2010): “A device that converts a continuous time signal into a discrete-time discrete-amplitude signal.”
ADC system	sequence of electronic components comprising (in this order) a hydrophone, a pre-amplifier, an AAF, and an ADC **NOTES**: System processing starts with the hydrophone converting pressure fluctuations into electrical ones. “System input” is therefore synonymous with “hydrophone input”. System processing ends with the ADC converting voltage fluctuations into digital counts. “System output” is therefore synonymous with “ADC output”.
ADC input	generic term referring to an analog representation of the time-varying current or voltage entering the ADC
ADC output **synonym**: system output	generic term referring to a digital representation of the ADC input, suitable for storage in a digital storage medium or processing on a digital computer **NOTES**: See also ‘integer ADC output’.
ping	Single transmission from a sonar projector
burst	sequence of pings closely spaced in time, over which the measured backscattering can be averaged to increase signal-to-noise ratio

crosstalk	undesired energy appearing in a signal as a result of coupling from other signals **NOTES**: Source: IEEE (STD-1241-2010)
receiver beam pattern **symbol**: $B_{\mathrm{Rx}}(\Omega)$	squared magnitude of the beamformer output in response to an acoustic plane wave, normalized by dividing by its maximum value in angle **NOTES**: **based on**: Ainslie (2010), p 252 The array geometry and processing, including the steering angle, need to be specified in sufficient detail to reproduce the beamformer output for the specified steering angle. The symbol Ω (for solid angle) indicates that the receiver beam pattern is a function of elevation (θ) and azimuth (ϕ). See also transmitter beam pattern.
transmitter beam pattern **symbol**: $B_{\mathrm{Tx}}(\Omega)$	source factor divided by its maximum value in angle **NOTES**: The symbol Ω (for solid angle) indicates the transmitter beam pattern is a function of elevation (θ) and azimuth (ϕ). See also receiver beam pattern.
full-scale signal	signal whose peak-to-peak value spans the entire range of input values recordable by an ADC, from minimum unsaturated voltage to maximum unsaturated voltage **NOTES**: Compare IEEE (STD-1241-2010, p 13): "A full-scale signal is one whose peak-to-peak amplitude spans the entire range of input values recordable by the analog-to-digital converter under test."
non-acoustic self-noise	fluctuations in the output of an acoustic receiver in the absence of sound pressure input at the hydrophone **NOTES**: Based on ISO (2017). EXAMPLE: Electrical noise.

Table 11. Acoustical terminology for ADEON hardware specification: Quantities used to characterize a hydrophone or hydrophone array.

Preferred term	Definition
free-field voltage sensitivity **synonym**: voltage sensitivity **symbol**: $M_{\mathrm{hp},V}$ **unit**: $\mathrm{V\ Pa^{-1}}$	ratio of the rms open-circuit output voltage to the rms spatially-averaged sound pressure in the undisturbed plane-progressive free field **NOTES**: Adapted from IEC (1994) (IEV 801-25-53) Free-field voltage sensitivity is a property of a voltage hydrophone, for a specified frequency band and a specified direction of sound incidence.
equivalent rms hydrophone noise sound pressure **symbol**: $p_{\mathrm{N,eq}}$ **unit**: Pa	ratio of the rms open-circuit output voltage to the free-field voltage sensitivity **NOTES**: Adapted from ISO (2017), entry 3.6.1.15 Equivalent rms hydrophone noise sound pressure includes contributions from both acoustic and non-acoustic noise.
hydrophone non-acoustic self-noise voltage **synonym**: self-noise voltage **unit**: V	open-circuit output voltage in the absence of sound pressure at the hydrophone input
hydrophone mean-square non-acoustic self-noise voltage spectral density **synonym**: self-noise voltage spectral density **unit**: $\mathrm{V^2/Hz}$	ratio of mean-square hydrophone non-acoustic self-noise voltage in a specified frequency band to the width of the frequency band
equivalent hydrophone mean-square non-acoustic self-noise sound pressure spectral density **synonym**: hydrophone self-noise sound pressure spectral density **unit**: $\mathrm{Pa^2/Hz}$	ratio of hydrophone mean-square non-acoustic self-noise voltage spectral density to the squared free-field voltage sensitivity
hydrophone self-noise spectral density **unit**: $\mathrm{Pa^2}$	mean-square self-noise voltage spectral density at the hydrophone output divided by the squared free-field open-circuit hydrophone voltage sensitivity
in-beam mean-square sound pressure **symbol**: p_{ib}^2 **unit**: $\mathrm{Pa^2}$	the quantity $p_{\mathrm{ib}}^2 = \iint p_{\Omega}^2(\Omega) B_{\mathrm{Rx}}(\Omega)\ \mathrm{d}\Omega,$ where $B_{\mathrm{Rx}}(\Omega)$ is the receiver beam pattern and $p_{\Omega}^2(\Omega)$ is the contribution to the mean-square sound pressure per unit solid angle **NOTES**: The symbol Ω (for solid angle) indicates the receiver beam pattern is a function of elevation (θ) and azimuth (ϕ).

in-beam power spectral density **symbol**: $p_{f,\mathrm{ib}}^2$ **unit**: Pa^2 /Hz	the quantity $p_{f,\mathrm{ib}}^2 = \iint p_{f,\Omega}^2(\Omega) B_{\mathrm{Rx}}(\Omega)\ \mathrm{d}\Omega,$ where $B_{\mathrm{Rx}}(\Omega)$ is the receiver beam pattern and $p_{f,\Omega}^2(\Omega)$ is the contribution to the mean-square sound pressure spectral density per unit solid angle **NOTES**: The symbol Ω (for solid angle) indicates the receiver beam pattern is a function of elevation (θ) and azimuth (ϕ).

Table 12. Acoustical terminology for ADEON hardware specification: Quantities used to characterize a digital sampling system, including pre-amplifier and anti-alias filter (AAF).

Preferred term	**Definition**
ADC input voltage **symbol**: v_{ADC} **unit**: 1	voltage at input to ADC
integer ADC output **symbol**: N_{ADC} **unit**: 1	integer representation of ADC output, defined such that a unit change in integer ADC output corresponds to a change in the least significant bit from 0 to 1 or from 1 to 0 **NOTES**: The integer ADC output is equal to the product of ADC input voltage and ADC sensitivity to voltage. The integer ADC output is one of $2^{N_{\mathrm{bit}}}$ consecutive integers, where N_{bit} is the bit depth. The integer ADC output is the ADC output when the ideal code bin width is equal to 1.
maximum integer ADC output **symbol**: $N_{\mathrm{ADC,max}}$ **unit**: 1	maximum possible value of the integer ADC output
minimum integer ADC output **symbol**: $N_{\mathrm{ADC,min}}$ **unit**: 1	minimum possible value of the integer ADC output **NOTES**: The integer ADC output can be positive or negative. If at least one value of the integer ADC output is negative, the minimum integer ADC output is also negative.
full-scale ADC output **symbol**: $N_{\mathrm{ADC,FS}}$ **unit**: 1	difference between maximum integer ADC output and minimum integer ADC output **NOTES**: The integer ADC output can be positive or negative. If the maximum integer ADC output is positive and the minimum integer ADC output is negative, then the full-scale ADC output is the sum of the maximum integer ADC output and the magnitude of the minimum integer ADC output.
bit depth **synonym**: word size **symbol**: N_{bit} **unit**: 1	number of bits at ADC output used to represent one value of ADC input
ADC sensitivity to voltage **symbol**: $M_{\mathrm{ADC},v}$ **unit**: V^{-1}	ratio of rms integer ADC output ($N_{\mathrm{ADC,rms}}$) to rms ADC input voltage ($v_{\mathrm{ADC,rms}}$) In equation form $M_{\mathrm{ADC},v} = \dfrac{N_{\mathrm{ADC,rms}}}{v_{\mathrm{ADC,rms}}}$ **NOTES**: Unless the ADC input voltage is equal to zero, the ADC sensitivity to voltage is also equal to the ratio of the integer ADC output to ADC input voltage.

ADC voltage conversion factor **symbol**: μ_V **unit**: V	reciprocal of ADC sensitivity to voltage
maximum unsaturated voltage **symbol**: $v_{\max}$ **unit**: V	maximum ADC input voltage for which the ADC sensitivity to voltage is independent of ADC input **NOTES**: The maximum unsaturated voltage is the maximum ADC input voltage for which the ADC sensitivity to voltage is linear with input voltage.
minimum unsaturated voltage **symbol**: $v_{\min}$ **unit**: V	minimum ADC input voltage for which the ADC sensitivity to voltage is independent of ADC input **NOTES**: The ADC input voltage can be positive or negative. If at least one value of the integer ADC input voltage is negative, the minimum unsaturated voltage is also negative.
full-scale input range **synonym**: full-scale voltage **abbreviation**: full-scale range; FSR	difference between maximum unsaturated voltage and minimum unsaturated voltage **NOTES**: The ADC input voltage can be positive or negative. If the maximum unsaturated voltage is positive and the minimum unsaturated voltage is negative, then the full-scale input range is the sum of the maximum unsaturated voltage and the magnitude of the minimum unsaturated voltage. Compare IEEE (STD-1241-2010) ('full-scale range', p13): "The difference between the most positive and most negative analog inputs of a converter's operating range. For an *N*-bit converter, FSR is given by: FSR = (2^N)x(ideal code width) in analog input units."
ideal code bin width **synonym**: ADC output step size **abbreviation**: ideal code width **symbol**: Q	full-scale input range divided by $N_{\mathrm{ADC,FS}} + 1$, where $N_{\mathrm{ADC,FS}}$ is the full-scale ADC output **NOTES**: The full-scale ADC output is equal to the total number of code bins plus one. Compare IEEE (2010) ('ideal code bin width', p14): "The ideal full-scale input range divided by the total number of code bins." Compare IEEE (2010) 'least significant bit', p14: "With reference to analog-to-digital converter input signal amplitude, an LSB [least significant bit] is synonymous with one ideal code bin width."
pre-amplifier voltage gain **symbol**: $G_{\mathrm{pA},V}$ **unit**: 1	ratio of rms pre-amplifier output voltage to rms pre-amplifier input voltage **NOTES**: The pre-amplifier voltage gain can vary with frequency. For a tonal signal, the pre-amplifier voltage is equal to the ratio of peak pre-amplifier output voltage to peak pre-amplifier input voltage.
AAF voltage gain **symbol**: $G_{\mathrm{AAF},V}$ **unit**: 1	ratio of rms AAF output voltage to rms AAF input voltage **NOTES**: The AAF voltage gain can vary with frequency.
non-acoustic self-noise voltage **symbol**: $v_{\mathrm{N,self}}$ **unit**: V	voltage at a specified location in an acoustic receiver in the absence of sound pressure input at the hydrophone

equivalent rms ADC noise voltage **symbol**: $v_{\mathrm{N,eq}}$ **unit**: V	quotient of the rms integer ADC output and the ADC sensitivity to voltage In equation form $$v_{\mathrm{N,eq}} = \frac{N_{\mathrm{ADC,rms}}}{M_{\mathrm{ADC},V}}$$ **NOTES**: Equivalent rms ADC noise voltage includes contributions from acoustic and non-acoustic noise.
equivalent rms ADC self-noise voltage **symbol**: $v_{\mathrm{N,eq,self}}$ **unit**: V	equivalent rms ADC noise voltage in the absence of ADC input
equivalent rms system self-noise voltage **unit**: V	equivalent rms ADC noise voltage in the absence of sound pressure at the hydrophone
ADC electronic self-noise output **unit**: 1	integer ADC output in the absence of ADC input **NOTES**: An absence of ADC input can be achieved by short-circuiting the ADC input.

Table 13. Acoustical terminology for ADEON hardware specification: Quantities used to characterize the passive data recorder acquisition system.

Preferred term	**Definition**
total system sensitivity **symbol**: M_{tot} **unit**: Pa^{-1}	ratio of rms integer ADC output to the rms spatially-averaged sound pressure in the undisturbed plane-progressive free field **NOTES**: For a voltage hydrophone, the total system sensitivity is related to the hydrophone and ADC sensitivities according to $M_{\mathrm{tot}} = M_{\mathrm{hp},V} G_{\mathrm{pA},V} G_{\mathrm{AAF},V} M_{\mathrm{ADC},V}$.
system non-acoustic self-noise output **synonym**: system self-noise output; ADC self-noise output **unit**: 1	system output in the absence of sound pressure at the hydrophone input
system mean-square non-acoustic self-noise output spectral density **synonym**: system self-noise output spectral density; ADC self-noise output spectral density **unit**: 1/Hz	distribution as a function of non-negative frequency of the *mean-square ADC non-acoustic self-noise output* per unit bandwidth of a sound having a continuous spectrum
equivalent system mean-square non-acoustic self-noise sound pressure spectral density **synonym**: system self-noise sound pressure spectral density	quotient of system mean-square non-acoustic self-noise output spectral density and the squared total system sensitivity

noise power **unit**: W	time-averaged product of noise current and noise voltage **NOTES**: In an electrical circuit of resistance, R, noise power is given by mean-square noise voltage divided by R or mean-square noise current multiplied by R. The noise power depends on the position in the processing chain at which it is determined. The position in the processing chain at which the noise is determined shall be specified. Compare IEEE (STD-1241-2010) ('noise (total)', p15): "Any deviation between the output signal (converted to input units) and the input signal except deviations caused by linear time-invariant system response (gain and phase shift), or a dc level shift. For example, noise includes the effects of random errors (random noise), fixed pattern errors, nonlinearities (e.g., harmonic or intermodulation distortion), and aperture uncertainty. See also: random noise."
signal power **symbol**: W_S **unit**: W	time-averaged product of signal current and signal voltage **NOTES**: In an electrical circuit of resistance, R, signal power is given by mean-square signal voltage divided by R or mean-square signal current multiplied by R. The signal power depends on the position in the processing chain at which it is determined. The position in the processing chain at which the signal is determined shall be specified.
signal-to-noise power ratio **synonym**: signal-to-noise ratio **symbol**: R_SN **unit**: 1	ratio of signal power to noise power **NOTES**: The signal-to-noise power ratio depends on the position in the processing chain at which it is determined. The position in the processing chain at which the signal-to-noise power ratio is determined shall be specified.
system self-noise spectral density **unit**: Pa^2	mean-square self-noise voltage spectral density at the system output divided by the squared system voltage sensitivity
system-weighted sound pressure **symbol**: p_sw **unit**: Pa	weighted sound pressure when the linear filter is the receiving system **NOTES**: See ISO (2017), entry 3.7.1.1. The receiving system might include a hydrophone, a pre-amplifier, and an ADC (including anti-alias filter). The receiving system shall be specified. A filter is a process that removes from a signal some component or feature. The linear filter might be chosen to characterize a specified frequency-dependent transfer function of a mechanical or electrical system.

Table 14. Terminology related to the operation and configuration of active acoustic echo sounders: quantities.

Quantity	**Definitions**
number of pings per burst **unit**: 1	number of individual pings in each burst
burst interval **unit**: s	difference between the start times of two consecutive bursts **NOTES**: See Lemon et al. (2012). The burst interval can be equal to the ping period.
pulse duration **synonym**: pulse length **unit**: s	duration of the transmitted ping **NOTES**: Usually expressed in milliseconds (ms)
digitization rate **unit**: hz	rate at which echo sounder samples are processed by the ADC when digitizing the returned acoustic signal
ping period **unit**: s	difference between the start times of two consecutive pings **NOTES**: See Lemon et al. (2012).
bin size **unit**: m	vertical dimension of the smallest ensonified volume an echo sounder can resolve **NOTES**: This definition assumes a vertically oriented echo sounder.
maximum range **unit**: m	distance, rounded to the nearest bin size, that an echo sounder listens for returns **NOTES**: Acoustic returns from objects further away than the maximum range are not recorded by the instrument.
lockout range **unit**: m	distance, rounded to the nearest bin size, after the pulse is transmitted over which an echo sounder ignores echoes
transmitter beamwidth **unit**: rad	angular extent of the beam within which the transmitter beam pattern continuously exceeds 0.5 **NOTES**: For a symmetrical beam, the transmitter beamwidth is twice the angle for which the transmitter beam pattern first falls below 0.5, relative to the beam axis.

6. Levels and Other Logarithmic Quantities Usually Expressed in Decibels

6.1. Level of a Power Quantity

In general, a level is a logarithm of a ratio of two like quantities. A widely used level in acoustics is the level of a power quantity (IEC 2002, Ainslie 2015). A power quantity is one that is proportional to power. The level of a power quantity, P, is the logarithm of that power quantity to a reference value of the same quantity, P_0 , defined such that:

$$L_P = 10 \log_{10} \frac{P}{P_0} \text{ dB} .$$

When expressing the value of a level of a power quantity in decibels, the reference value, P_0, shall be specified. Table 15 lists some common examples, with standard reference values.

Table 15. Examples of level of a power quantity, and associated reference values for sound in water (ISO 2015, 2017). For comparison, the final column lists corresponding reference values for sound in air (ISO 2015).

Level, L_p	**Power quantity, P**	**Reference value (sound in water), P_0**	**Reference value (sound in air), P_0**
Sound exposure level (SEL)	Sound exposure	$1\ \mu\mathrm{Pa}^2\ \mathrm{s}$	$400\ \mu\mathrm{Pa}^2\ \mathrm{s}$
Mean-square sound pressure spectral density level (PSDL)	Mean-square sound pressure spectral density	$1\ \mu\mathrm{Pa}^2/\mathrm{Hz}$	$400\ \mu\mathrm{Pa}^2/\mathrm{Hz}$
Sound power level (SWL)	Sound power	$1\ \mathrm{pW}$	$1\ \mathrm{pW}$
Sound pressure level (SPL)	Mean-square sound pressure	$1\ \mu\mathrm{Pa}^2$	$400\ \mu\mathrm{Pa}^2$
Source level (SL)	source factor	$1\ \mu\mathrm{Pa}^2\ \mathrm{m}^2$	NA

6.2. Level of a Field Quantity

The level of a field quantity is also widely used in acoustics is (IEC 2002). A field quantity is one whose square is proportional to power. The level of a field quantity, F, is the logarithm of the ratio of that field quantity to a reference value of the same quantity, F_0 , defined such that:

$$L_F = 20 \log_{10} \frac{F}{F_0} \text{ dB} .$$

When expressing the value of a level of a field quantity in decibels, the reference value, F_0, shall be specified. Table 16 lists some examples, with standard reference values. The levels (of the listed field quantities) defined in Table 16 have identical values to the levels of the corresponding power quantities listed in Table 15. The reason for providing both definitions is to clarify that the choice between P_0 (say 1 µPa^2/Hz) and F_0 (1 µPa/Hz$^{1/2}$) for the reference quantity makes no difference to the value of the level. The level of a power quantity is identical to the level of the corresponding field quantity, defined as the square root of the power quantity (also known as a ‘root-power quantity’ (Ainslie 2015)).

Table 16. Examples of level of a field quantity, and associated reference values for sound in water (ISO 2015, 2017). For comparison, the final column lists corresponding reference values for sound in air (ISO 2015).

Level, L_F	**Field quantity, F**	**Reference value (sound in water), F_0**	**Reference value (sound in air), F_0**
Sound exposure level (SEL)	Root-sound exposure	$1\ \mu\text{Pa s}^{\frac{1}{2}}$	$20\ \mu\text{Pa s}^{\frac{1}{2}}$
Mean-square sound pressure spectral density level (PSDL)	Square root of the mean-square sound pressure spectral density	$1\ \mu\text{Pa}/\text{Hz}^{\frac{1}{2}}$	$20\ \mu\text{Pa}/\text{Hz}^{\frac{1}{2}}$
Sound power level (SWL)	Root-sound power	$1\ \text{pW}^{\frac{1}{2}}$	$1\ \text{pW}^{\frac{1}{2}}$
Sound pressure level (Lrms or SPL)	Root-mean-square sound pressure	$1\ \mu\text{Pa}$	$20\ \mu\text{Pa}$
Source level (SL)	Root-source factor	$1\ \mu\text{Pa m}$	NA

6.3. Reference Values Shall be Reported as a Power Quantity

In the acoustics literature, one sometimes encounters a power quantity used as the reference value (e.g., $1\ \mu\text{Pa}^2$, $1\ \mu\text{Pa}^2\text{s}$, $1\ \mu\text{Pa}^2/\text{Hz}$, or $1\ \mu\text{Pa}^2\text{s}/\text{Hz}$) and sometimes the corresponding root-power quantity ($1\ \mu\text{Pa}$, $1\ \mu\text{Pa s}^{1/2}$, $1\ \mu\text{Pa}/\text{Hz}^{1/2}$, or $1\ \mu\text{Pa s}^{1/2}/\text{Hz}^{1/2}$). The root-power reference value for the energy spectral density level (ESDL), $1\ \mu\text{Pa s}^{1/2}/\text{Hz}^{1/2}$, is sometimes simplified to the (equivalent) $1\ \mu\text{Pa}/\text{Hz}$. The unit symbol $1\ \mu\text{Pa}/\text{Hz}$ is easily confused with (and sometimes used as shorthand for) $1\ \mu\text{Pa}^2/\text{Hz}$, which is the power reference value of the *power* spectral density level (PSDL), representing a different physical quantity. The intended meaning is identical whether a power or root-power reference quantity is stated, but the proliferation of mixed power and root-power reference values can cause confusion.

An additional source of confusion is the widespread use of "$1\ \mu\text{Pa}$ @ 1 m", "$1\ \mu\text{Pa}^2\ \text{s}$ @ 1 m", and similar as a reference value for source level. Using this convention gives the impression that one is referring to a value of SPL or SEL at a distance of 1 m from the source, whereas the source level is actually a far-field quantity, whose numerical value only rarely, if ever, coincides with that of SPL at 1 m. The appropriate power quantity reference values compatible with ISO (2017) are $1\ \mu\text{Pa}^2\ \text{m}^2$ and $1\ \mu\text{Pa}^2\text{m}^2\ \text{s}$, or $1\ \mu\text{Pa m}$ and $1\ \mu\text{Pa m s}^{1/2}$ for the corresponding root-power quantities.

To reduce the risk of confusion, ADEON has made the following choices for reporting reference values:

- The reference value shall be a power quantity (not a root-power quantity or field quantity). The nature of the power quantity shall be specified.
- When reporting levels, the reference value P_0 of the specified power quantity shall also be specified (Ainslie (2015) provides a history of reference values used in underwater acoustics).
- Specifically for quantities listed in Table 17, the reference values shall be those of the right-hand column of that table.

Table 17. The reference values in this table shall be used. All are compliant with ISO (2017).

Term	Abbreviation	Symbol	Unit	Power quantity	Reference value
Mean-square sound pressure level	Lrms or SPL	$L_{p,\mathrm{rms}}$	dB	Mean-square sound pressure	$1\ \mu\mathrm{Pa}^2$
Peak sound pressure level	Lpk	$L_{p,\mathrm{pk}}$	dB	Squared peak sound pressure	$1\ \mu\mathrm{Pa}^2$
Sound exposure level	SEL	L_E	dB	Sound exposure	$1\ \mu\mathrm{Pa}^2\ \mathrm{s}$
Source level	SL	L_S	dB	Source factor	$1\ \mu\mathrm{Pa}^2\ \mathrm{m}^2$
Propagation loss	PL	N_PL	dB	Reciprocal propagation factor	$1\ \mathrm{m}^2$
Transmission loss	TL	ΔL_TL	dB	NA	NA
Mean-square sound pressure spectral density level	PSDL	$L_{p,f}$	dB	Mean-square sound pressure spectral density	$1\ \mu\mathrm{Pa}^2/\mathrm{Hz}$
Sound exposure spectral density level	ESDL	$L_{E,f}$	dB	Sound exposure spectral density	$1\ \mu\mathrm{Pa}^2\ \mathrm{s}/\mathrm{Hz}$

6.4. Definitions of Levels and Other Logarithmic Quantities Usually Expressed in Decibels

6.4.1. Terms and Terminology

Tables 18 to 21 define levels and other logarithmic quantities usually expressed in decibels. A deliberate choice is made to define levels in terms of power quantities and to use the reference values of those power quantities (P_0), and not of the corresponding field quantities (F_0).

Table 18. Levels and other logarithmic quantities usually expressed in decibels: Sound field metrics.

Quantity	Definition
mean-square sound pressure level **synonym**: root-mean-square sound pressure level; sound pressure level **abbreviation**: SPL; Lrms **deprecated**: rms SPL; root-mean-square SPL; mean-square SPL **symbol**: L_p; $L_{p,\mathrm{rms}}$	level of the mean-square sound pressure In equation form $L_{p,\mathrm{rms}} = 10 \lg \frac{p_\mathrm{rms}^2}{p_0^2}\ \mathrm{dB}$ Reference value: $p_0^2 = 1\ \mu\mathrm{Pa}^2$ **NOTES**: Based on ISO (2017), entry 3.2.1.1 SPL is also equal to the level of the field quantity root-mean-square sound pressure.
time-integrated squared sound pressure level **synonym**: sound exposure level; sound pressure exposure level **abbreviation**: SEL **symbol**: $L_{E,p}$ **reference value**: 1 μPa² s	level of the time-integrated squared sound pressure In equation form $L_{E,p} = 10 \lg \frac{E}{E_0}\ \mathrm{dB}$ Reference value: $E_0 = 1\ \mu\mathrm{Pa}^2\mathrm{s}$ **NOTES**: Based on ISO (2017), entry 3.2.1.5

sound exposure spectral density level **synonym**: energy spectral density level (ESDL) **symbol**: $L_{E,f}$ **reference value**: 1 μPa² s/Hz	level of the sound exposure spectral density In equation form $L_{E,f} = 10 \lg \frac{E_f}{E_{f,0}}$ dB Reference value: $E_{f,0} = 1\ \mu\mathrm{Pa}^2\mathrm{s/Hz}$ **NOTES**: Based on ISO (2017), entry 3.2.1.9
mean-square sound pressure spectral density level **synonym**: power spectral density level (PSDL) **symbol**: $L_{p,f}$ **reference value**: 1 μPa²/Hz	level of the mean-square sound pressure spectral density In equation form $L_{p,f} = 10 \lg \frac{\left(\overline{p^2}\right)_f}{\left(\overline{p^2}\right)_{f,0}}$ dB Reference value: $\left(\overline{p^2}\right)_{f,0} = 1\ \mu\mathrm{Pa}^2/\mathrm{Hz}$ **NOTES**: Based on ISO (2017), entry 3.2.1.10
zero-to-peak sound pressure level **synonym**: peak sound pressure level **abbreviation**: Lpk **deprecated**: peak SPL **symbol**: $L_{p,0\text{-pk}}$; $L_{p,\text{pk}}$	level of the squared zero-to-peak sound pressure In equation form $L_{p,0\text{-pk}} = 10 \lg \frac{p_{0\text{-pk}}^2}{p_0^2}$ dB Reference value: $p_0^2 = 1\ \mu\mathrm{Pa}^2$ **NOTES**: Based on ISO (2017), entry 3.2.2.1

Table 19. Levels and other logarithmic quantities usually expressed in decibels: Source metrics.

Quantity	Definition
source level **abbreviation**: SL **symbol**: L_S	level of the source factor In equation form $L_S = 10 \lg \frac{F_S}{F_{S,0}}$ dB Reference value: $F_{S,0} = 1\ \mu\mathrm{Pa}^2\mathrm{m}^2$ **NOTES**: based on ISO (2017), entry 3.3.2.1
source spectral density level **synonym**: source spectrum level **abbreviation**: SSL **symbol**: $L_{S,f}$	level of the source factor spectral density In equation form $L_{S,f} = 10 \lg \frac{F_{S,f}}{F_{S,f,0}}$ dB Reference value: $F_{S,f,0} = 1\ \mu\mathrm{Pa}^2\mathrm{m}^2/\mathrm{Hz}$ **NOTES**: Source factor spectral density is a power quantity.

surface-affected source spectral density level **synonym**: surface-affected source spectrum level **abbreviation**: SASSL **symbol**: $L'_{S,f}$	level of the surface-affected source factor spectral density In equation form $L'_{S,f} = 10\lg\frac{F'_{S,f}}{F_{\mathrm{S},f,0}}\ \mathrm{dB}$ Reference value: $F_{\mathrm{S},f,0} = 1\ \mathrm{\mu Pa^2 m^2/Hz}$ **NOTES**: Surface-affected source factor spectral density is a power quantity.
areic source spectral density level **synonym**: areic source spectrum level **abbreviation**: ASSL **symbol**: $L_{\mathrm{S},f,A}$	level of the areic source factor spectral density In equation form $L_{\mathrm{S},f,A} = 10\lg\frac{F_{\mathrm{S},f,A}}{F_{\mathrm{S},f,A,0}}\ \mathrm{dB}$ Reference value: $F_{\mathrm{S},f,A,0} = 1\ \mathrm{\mu Pa^2 m^2/(m^2 Hz)}$ **NOTES**: Areic source factor spectral density is a power quantity.
energy source spectral density level **synonym**: energy source spectrum level **abbreviation**: ESSL **symbol**: $L_{\mathrm{S},E,f}$	level of the energy source factor spectral density In equation form $L_{\mathrm{S},E,f} = 10\lg\frac{F_{S,E,f}}{F_{S,E,f,0}}\ \mathrm{dB}$ Reference value: $F_{S,E,f,0} = 1\ \mathrm{\mu Pa^2 m^2/Hz}$ **NOTES**: Energy source factor spectral density is a power quantity.
surface-affected energy source spectral density level **synonym**: surface-affected energy source spectrum level **abbreviation**: SAESSL **symbol**: $L'_{\mathrm{S},E,f}$	level of the surface-affected energy source factor spectral density In equation form $L'_{\mathrm{S},E,f} = 10\lg\frac{F'_{\mathrm{S},E,f}}{F_{\mathrm{S},E,f,0}}\ \mathrm{dB}$ Reference value: $F_{\mathrm{S},E,f,0} = 1\ \mathrm{\mu Pa^2 m^2/Hz}$ **NOTES**: Surface-affected energy source factor spectral density is a power quantity.
areic surface-affected source spectral density level **synonym**: areic surface-affected source spectrum level **abbreviation**: ASASSL **symbol**: $L'_{\mathrm{S},f,A}$	level of the areic surface-affected source factor spectral density In equation form $L'_{\mathrm{S},f,A} = 10\lg\frac{F'_{\mathrm{S},f,A}}{F_{\mathrm{S},f,A,0}}\ \mathrm{dB}$ Reference value: $F_{\mathrm{S},f,A,0} = 1\ \mathrm{\mu Pa^2 m^2/(m^2 Hz)}$ **NOTES**: Areic surface-affected source factor spectral density is a power quantity.

Table 20. Levels and other logarithmic quantities usually expressed in decibels: Propagation and scattering metrics.

Quantity	Definition
transmission loss **abbreviation**: TL **symbol**: N_{TL}	reduction in a specified level between two specified points x_1, x_2 that are within an underwater acoustic field In equation form, if the specified level is sound pressure level $\Delta L_{\mathrm{TL}} = L_{p,\mathrm{rms}}(\boldsymbol{x}_1) - L_{p,\mathrm{rms}}(\boldsymbol{x}_2)$ or equivalently, using the definition of sound pressure level $L_{p,\mathrm{rms}}$ $N_{\mathrm{TL}}(\boldsymbol{x}) = 10\,\lg\frac{p^2_{\mathrm{rms}}(\boldsymbol{x}_1)}{p^2_{\mathrm{rms}}(\boldsymbol{x}_2)}\ \mathrm{dB}\,.$ **NOTES**: Source: ISO (2017), entry 3.4.1.3 Transmission loss is the difference between two like levels and therefore has no reference value. Compare ‘propagation loss’.
propagation loss **abbreviation**: PL **symbol**: N_{PL}	the quantity $N_{\mathrm{PL}}(\boldsymbol{x}) = 10\,\lg\frac{F(\boldsymbol{x})^{-1}}{F_0^{-1}}\ \mathrm{dB}\,,$ where $F(\boldsymbol{x})$ is the propagation factor (ISO 2017; entry 3.3.1.6), defined as the ratio of mean-square sound pressure (p^2_{rms}) to source factor (S), such that $F(\boldsymbol{x}) = \frac{p^2_{\mathrm{rms}}(\boldsymbol{x})}{S}\,,$ and therefore $F(\boldsymbol{x})^{-1} = \frac{S}{p^2_{\mathrm{rms}}(\boldsymbol{x})}\,.$ Reference value: $F_0^{-1} = 1\ \mathrm{m}^2$ **NOTES**: The formal definition of ‘propagation loss’ according to ISO (2017) (entry 3.4.1.4) is: “difference between *source level* (3.3.2.1) in a specified direction, L_{S}, and *mean-square sound pressure level* (3.2.1.1), $L_p(x)$, at a specified position, x”. In equation form $N_{\mathrm{PL}}(\boldsymbol{x}) = L_{\mathrm{S}} - L_{p,\mathrm{rms}}(\boldsymbol{x}),$ or equivalently, using the definitions of source level L_{S} and sound pressure level $L_{p,\mathrm{rms}}$ $N_{\mathrm{PL}}(\boldsymbol{x}) = 10\,\lg\frac{S/p^2_{\mathrm{rms}}(\boldsymbol{x})}{S_0/p_0^2}\ \mathrm{dB}.$ This equation is equivalent to our definition of ‘propagation loss’ as the level of the reciprocal propagation factor, and explains the origin of $F_0^{-1} = S_0/p_0^2 = 1\ \mathrm{m}^2$ as the reference value for propagation loss. Compare ‘transmission loss’.
volume backscattering strength **abbreviation**: VBS **symbol**: $S_{\mathrm{v,bs}}$	volume scattering strength evaluated in the backscattering direction **NOTES**: The volume backscattering strength is related to the volume backscattering coefficient ($s_{\mathrm{v,bs}}$) according to $S_{\mathrm{v,bs}} = 10\log_{10}\frac{s_{\mathrm{v,bs}}}{\sigma_{\mathrm{v},0}}\ \mathrm{dB}$ where the reference value is: $\sigma_{\mathrm{v},0} = 1\ \mathrm{m}^2\ \mathrm{sr}^{-1}/\mathrm{m}^3$ The subscript ‘bs’ may be omitted if no ambiguity results from doing so. The factor sr^{-1} in the reference value is equal to unity. Thus the reference value may be written $\sigma_{\mathrm{v},0} = 1\ \mathrm{m}^2/\mathrm{m}^3$ or $\sigma_{\mathrm{v},0} = 1\ \mathrm{m}^{-1}$ where no ambiguity results from doing so. The backscattering direction is aligned with the vector from scatterer to source.

area backscattering strength **abbreviation**: ABS **symbol**: S_a **unit:** dB	the quantity $S_\mathrm{a} = 10\log_{10}\frac{s_\mathrm{a}}{\sigma_{\mathrm{a},0}}\,\mathrm{dB}$ where s_a is the area backscattering coefficient Reference value: $\sigma_{\mathrm{a},0} = 1\ \ \mathrm{m}^2\ \mathrm{sr}^{-1}/\mathrm{m}^2$ **NOTES**: The area backscattering strength is a property of the sea volume. Though it shares the same reference value, it differs from the surface backscattering strength, which is a property of the sea surface. The factor sr^{-1} in the reference value is equal to unity. Thus the reference value may be written $\sigma_{\mathrm{v},0} = 1\ \mathrm{m}^2/\mathrm{m}^2$ or omitted altogether where no ambiguity results from doing so.

Table 21. Levels and other logarithmic quantities usually expressed in decibels: receiver metrics. See also Figure 3.

Quantity	Definition
voltage sensitivity level **symbol**: $L_{M,v}$	the quantity $L_{M,v}\ = 10\,\mathrm{lg}\frac{M_{\mathrm{hp},v}^2}{M_{v,0}^2}\ \mathrm{dB},$ where $M_{\mathrm{hp},v}$ is the free-field voltage sensitivity Reference value: $M_{v,0}^2 = 1\ V^2/\mathrm{\mu Pa}^2$
signal-to-noise level difference **symbol**: ΔL_SN	the quantity $\Delta L_\mathrm{SN}\ = 10\,\mathrm{lg}\,R_\mathrm{SN}\ \mathrm{dB},$ where R_SN is the signal-to-noise power ratio Reference value: NA
hydrophone spectral noise floor level **symbol**: $L_{\mathrm{N,eq},f,\mathrm{hp}}$	level of the hydrophone self-noise spectral density In equation form $L_{\mathrm{N,eq},f,\mathrm{hp}}\ = 10\,\mathrm{lg}\frac{\left(p_\mathrm{N,eq}^2\right)_f}{p_0^2/f_0}\ \mathrm{dB},$ where $\left(p_\mathrm{N,eq}^2\right)_f$ is the hydrophone self-noise spectral density Reference value: $p_0^2/f_0 = 1\ \mathrm{\mu Pa}^2/\mathrm{Hz}$
system spectral noise floor level **synonym**: recorder spectral noise floor level **symbol**: $L_{\mathrm{N,eq},f,sys}$	level of the system self-noise spectral density In equation form $L_{\mathrm{N,eq},f,sys}\ = 10\,\mathrm{lg}\frac{\left(p_\mathrm{N,eq}^2\right)_f}{p_0^2/f_0}\ \mathrm{dB},$ where $\left(p_\mathrm{N,eq}^2\right)_f$ is the system self-noise spectral density Reference value: $p_0^2/f_0 = 1\ \mathrm{\mu Pa}^2/\mathrm{Hz}$
ADC dynamic range **symbol**: $\Delta L_\mathrm{DR,ADC}$	the quantity $\Delta L_\mathrm{DR,ADC}\ = 10\,\mathrm{lg}\frac{\overline{v_\mathrm{FS}^2}}{v_\mathrm{N,eq,self}^2}\ \mathrm{dB},$ where $\overline{v_\mathrm{FS}^2}$ is the mean-square voltage of a sinusoidal full-scale signal and $v_\mathrm{N,eq,self}$ is the equivalent rms ADC self-noise voltage Reference value: NA

system dynamic range **symbol**: $\Delta L_{\mathrm{DR,sys}}$	the quantity $\Delta L_{\mathrm{DR,sys}} = 10\lg\frac{\overline{v_{\mathrm{FS}}^2}}{v_{\mathrm{N,eq,self}}^2 + \overline{v_{\mathrm{N,self}}^2}}\ \mathrm{dB},$ where $\overline{v_{\mathrm{FS}}^2}$ is the mean-square voltage of a sinusoidal full-scale signal, $v_{\mathrm{N,eq,self}}$ is the equivalent rms ADC self-noise voltage and $v_{\mathrm{N,self}}$ is the non-acoustic self-noise voltage at the ADC input Reference value: NA
total harmonic distortion **abbreviation**: THD	the quantity $\Delta L_{\mathrm{DR}} = 10\lg\frac{v_2^2 + v_3^2 \ldots + v_{n+1}^2}{v_1^2}\ \mathrm{dB},$ where v_1 is the rms voltage of a sinusoidal full-scale signal and $v_2 \ldots v_{n+1}$ are the mean-square ADC self-noise voltage of the first n harmonics **NOTES**: Compare IEEE (STD-1241-2010, p 17): “For a pure sine-wave input of specified amplitude and frequency, the root-sum-of-squares (rss) of all the harmonic distortion components including their aliases in the spectral output of the analog-to-digital converter. Unless otherwise specified, THD is estimated by the rss of the second through the tenth harmonics, inclusive. THD is often expressed as a decibel ratio with respect to the root-mean-square amplitude of the output component at the input frequency.”
in-beam sound pressure level **symbol**: $L_{p,\mathrm{ib}}$ **unit**: dB	the quantity $L_{p,\mathrm{ib}} = 10\lg\frac{p_{\mathrm{ib}}^2}{p_0^2}\ \mathrm{dB},$ where p_{ib}^2 is the in-beam mean-square sound pressure Reference value: $p_0^2 = 1\ \mu\mathrm{Pa}^2$
in-beam mean-square sound pressure spectral density level **abbreviation**: in-beam power spectral density level **symbol**: $L_{p,f,\mathrm{ib}}$ **unit**: dB	The quantity $L_{p,f,\mathrm{ib}} = 10\lg\frac{p_{f,\mathrm{ib}}^2}{p_0^2/f_0}\ \mathrm{dB},$ where $p_{f,\mathrm{ib}}^2$ is the in-beam mean-square sound pressure spectral density Reference value: $p_0^2/f_0 = 1\ \mu\mathrm{Pa}^2/\mathrm{Hz}$ **NOTES**: See Ainslie (2010), p 62 and 601
system-weighted sound pressure level **symbol**: $L_{p,\mathrm{sw}}$	level of the mean-square system-weighted sound pressure In equation form $L_{p,\mathrm{sw}} = 10\lg\frac{\overline{p_{\mathrm{sw}}^2}}{p_0^2}\ \mathrm{dB}$ where $\overline{p_{\mathrm{sw}}^2}$ is the in-beam mean-square system-weighted sound pressure reference value: $p_0^2 = 1\ \mu\mathrm{Pa}^2$

6.4.2. Dynamic Range

Consider the quantity $x(t)$:

$$x(t) = x_{\mathrm{FS}}(t) + x_{\mathrm{N}}(t)\,,$$

where $x_{\mathrm{FS}}(t)$ is a sinusoidal full-scale signal at ADC input and $x_{\mathrm{N}}(t)$ is the quotient of the ADC electronic self-noise output and the ADC sensitivity to voltage:

$$x = \frac{N_{\mathrm{ADC,self}}}{M_{\mathrm{ADC},v}}\,.$$

The Fourier transform of the digital output is:

$$X(f) = X_{\mathrm{FS}}(f) + X_{\mathrm{N}}(f)\,.$$

Here, $X_{\mathrm{FS}}(f)$ is the Fourier transform of the full-scale signal and $X_{\mathrm{N}}(f)$ is the Fourier transform of the noise.

The quantities $x(t)$ and $X(f)$ form a Fourier transform pair (Section 2.2):

$$X(f) = \int_{-\infty}^{+\infty} x(t)\exp(-2\pi i f t)\,\mathrm{d}t$$

$$x(t) = \int_{-\infty}^{+\infty} X(f)\exp(+2\pi i f t)\,\mathrm{d}f\,.$$

In practice, a discrete Fourier transform is used (Section 2.3):

$$X(f_m) = \delta t \sum_{n=0}^{M-1} x(t_n)\exp(-2\pi i \; nm/M)$$

$$x(t_n) = \frac{1}{M\delta t}\sum_{m=0}^{M-1} X(f_m)\exp(+2\pi i \; nm/M)\,.$$

Taking the modulus squared and dividing by $\max|X_{\mathrm{FS}}(f)|^2$ gives the quantity

$$Q(f) = \frac{|X(f)|^2}{\max|X_{\mathrm{FS}}(f)|^2} = \frac{|X_{\mathrm{FS}}(f) + X_{\mathrm{N}}(f)|^2}{\max|X_{\mathrm{FS}}(f)|^2}\,,$$

where f_{FS} is the frequency of the full-scale signal. The quantity

$$\Delta L(f) = 10\lg Q(f)\ \mathrm{dB}$$

is plotted in Figure 3 and explained further in Table 22.

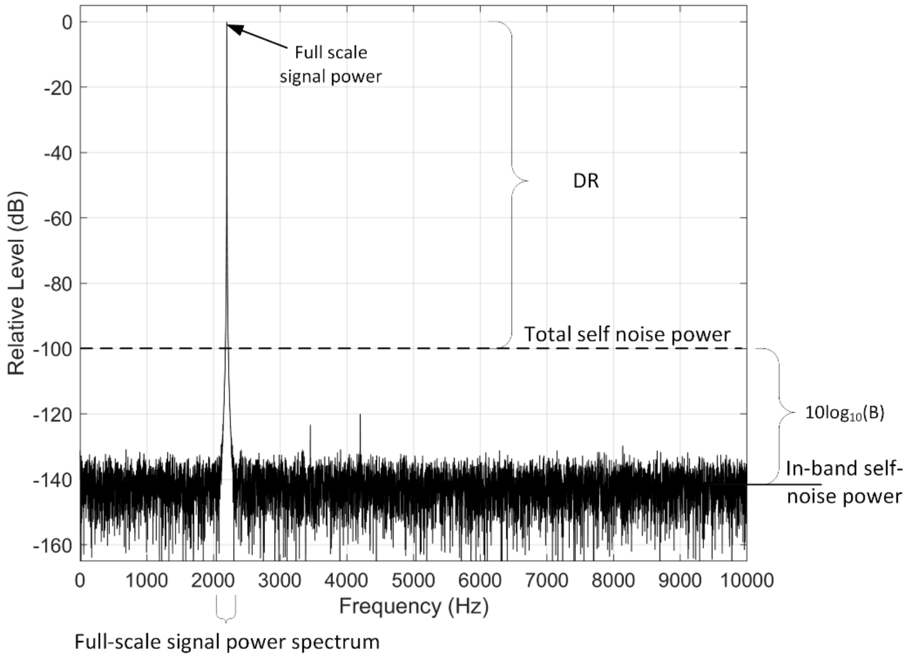


Figure 3. Normalized power spectra converted to relative level, in decibels, $\Delta L/\mathrm{dB} = 10\lg Q(f)$, where $Q(f)$ is a normalized power spectrum (Table 22). Dynamic range (DR) is also shown.

Table 22. Definition of quantities illustrated by Figure 3. $Q = 10^{\Delta L/\,(10\ \mathrm{dB})}$, such that $\Delta L = 10\lg Q(f)\ \mathrm{dB}$. Here f_{FS} is the frequency of a sinusoidal full-scale signal and $X_{\mathrm{FS}}(f_{\mathrm{FS}})$ is the value of $X_{\mathrm{FS}}(f)$ evaluated at that frequency.

Quantity*	**Definition**	**Notes**
Full-scale (FS) signal power spectrum $Q_{\mathrm{FS}}(f) = \frac{T^2}{2}\frac{S_{\mathrm{FS}}(f)}{\max\lvert X_{\mathrm{FS}}(f)\rvert^2}$	$S_{\mathrm{FS}}(f) = \frac{2}{T^2}\lvert X_{\mathrm{FS}}(f)\rvert^2$	$Q_{\mathrm{FS}}(f) = \frac{\lvert X_{\mathrm{FS}}(f)\rvert^2}{\max\lvert X_{\mathrm{FS}}(f)\rvert^2}$
In-band self-noise power, "spectral noise floor" $Q_{\mathrm{N},f}(f) = \frac{T^2}{2}\frac{S_{\mathrm{N}}(f)}{\max\lvert X_{\mathrm{FS}}(f)\rvert^2}$	$S_{\mathrm{N}}(f) = \frac{2}{T^2}\lvert X_{\mathrm{N}}(f)\rvert^2$	$Q_{\mathrm{FS}}(f) = \frac{\lvert X_{\mathrm{N}}(f)\rvert^2}{\max\lvert X_{\mathrm{FS}}(f)\rvert^2}$
Total self-noise power (added over all bands) $Q_N = \frac{T^2}{2}\frac{\overline{x_{\mathrm{N}}^2}}{\max\lvert X_{\mathrm{FS}}(f)\rvert^2}$	Continuum form: $\overline{x_{\mathrm{N}}^2} = \frac{2}{M\delta t}\int_0^{+\infty}\lvert X_{\mathrm{N}}\rvert^2 \mathrm{d}f$ Discrete form: $\overline{x_{\mathrm{N}}^2} = \frac{1}{(M\delta t)^2}\sum_{m=0}^{M-1}\lvert X_{\mathrm{N}}(f_m)\rvert^2$	Continuum form: $Q_{\mathrm{N}} = T\int_0^{\infty} Q_{\mathrm{N},f}(f)\,\mathrm{d}f$ Discrete form: $Q_{\mathrm{N}} = \sum_{m=0}^{M-1} Q_{\mathrm{N},f}(f_m)$
Dynamic range (DR)	(FS signal power) / (total self-noise power) $R_{\mathrm{DR}} = \frac{\overline{x_{\mathrm{FS}}^2}}{\overline{x_{\mathrm{N}}^2}}$	The DR is $10\log_{10} R_{\mathrm{DR}}\ \mathrm{dB}$

* Label in Figure 3.

The FS signal power is:

$$\overline{x_{\mathrm{FS}}^2} = \frac{2}{T}\int_0^{+\infty} |X_{\mathrm{FS}}|^2 \mathrm{d}f$$

$$\overline{x_{\mathrm{FS}}^2} = \frac{1}{(M\delta t)^2}\sum_{m=0}^{M-1} |X_{\mathrm{FS}}(f_m)|^2 \, .$$

If the signal bandwidth is smaller than the frequency resolution δf of the DFT,

$$\delta f = \frac{1}{M\delta t},$$

the FS signal power is given approximately by:

$$\overline{x_{\mathrm{FS}}^2} \approx \frac{2}{(M\delta t)^2} \max |X_{\mathrm{FS}}(f)|^2 \, .$$

According to Plancherel's theorem, the energy in the time domain is equal to the energy in the frequency domain:

$$\int_{-\infty}^{+\infty} |X(f)|^2 \mathrm{d}f = \int_{-\infty}^{+\infty} x(t)^2 \mathrm{d}t \, .$$

The corresponding property (Parseval's theorem) for a DFT pair is:

$$\frac{1}{M\delta t}\sum_{m=0}^{M-1} |X_{\mathrm{FS}}(f_m)|^2 = \delta t \sum_{n=0}^{M-1} x(t_n)^2 \, .$$

The signal power is therefore (continuum form):

$$\overline{x^2} := \frac{1}{T}\int_{-T/2}^{+T/2} x(t)^2 \mathrm{d}t = \frac{2}{T}\int_0^{+\infty} |X(f)|^2 \mathrm{d}f$$

or (discrete form)

$$\overline{x^2} := \frac{\delta t}{M\delta t}\sum_{n=0}^{M-1} x(t_n)^2 = \frac{1}{(M\delta t)^2}\sum_{m=0}^{M-1} |X_{\mathrm{FS}}(f_m)|^2 .$$

6.5. Acoustical Terminology for Soundscape Data Processing

Terminology for soundscape data processing is defined in Table 23.

Table 23. Soundscape terminology: processing windows and statistical measures.

Preferred term	Definition
N percent temporal exceedance level **symbol**: $L_{t,N\%}$	mean-square sound pressure level that is exceeded for $N\%$ of the time in a specified temporal analysis window **NOTES**: Based ISO (2003), entry 3.1.3. The frequency band, location, and duration of the temporal observation window shall be specified.
Nth temporal level percentile	value of mean-square sound pressure level below which $N\%$ of observations fall, in a specified temporal analysis window **NOTES**: Based on ISO (2013): “value of a variable below which a certain percentage of observations fall”. The frequency band, location, and duration of the temporal observation window shall be specified.
N percent spatial exceedance level **symbol**: $L_{x,N\%}$	mean-square sound pressure level that is exceeded for $N\%$ of the space in a specified spatial analysis window **NOTES**: The frequency band, duration of the temporal observation window, and volume, shape and location of the spatial observation window shall be specified.
Nth spatial level percentile	value of mean-square sound pressure level below which $N\%$ of observations fall, in a specified spatial analysis window **NOTES**: The frequency band, duration of the temporal observation window, and volume, shape and location of the spatial observation window shall be specified.

7. Soundscape Reporting

7.1. Reporting Quantities (General)

Unless otherwise specified, reporting shall follow the E&P Sound and Marine Life Joint Industry Programme (JIP) reporting standard Ainslie and de Jong (2018), henceforth abbreviated “JIP UA-R”. UA-R follows the International System of Quantities (ISQ) (ISO 2009), with appropriate exceptions from IEEE 260.1-2004 (STD-260.1-2004).

In the ISQ, a quantity Q is written

$$Q = x\,U\,,$$

where U is the unit in which the quantity is expressed and x is a dimensionless number equal to Q/U (the numerical value of Q when expressed in the unit U). The value of Q may be reported either in the form:

$$Q = x\,U\,,$$

or (dividing both sides by U):

$$\frac{Q}{U} = x\,.$$

7.2. Reporting Levels and Other Quantities Usually Reported in Decibels

Levels (L), sensitivity levels (N_M), and level differences (ΔL) are reported in decibels. Three alternative styles are described below. One of these three styles shall be followed consistently in any one document.

7.2.1. Style 1 (Reference Value as Level Modifier)

Style 1 follows IEC 60027-3 (IEC 2002). According to IEC (2002), the level L of a power quantity P may be reported in the form:

$$L_P(\mathrm{re}\ P_0) = x\ \mathrm{dB}\,,$$

where P_0 is the reference value. For example, if the sound exposure level relative to E_0 is 140 dB ($x = 140$), this is written:

$$L_E(\mathrm{re}\ E_0) = 140\ \mathrm{dB}\,.$$

In this equation, the unit is the decibel (dB) and the reference value is E_0.

The sensitivity level (symbol N) is:

$$N_S(\mathrm{re}\ S_0) = y\ \mathrm{dB}\,,$$

where S_0 is the reference value. For example, if the hydrophone sensitivity level relative to M_0 is $-110\ \mathrm{dB}$ ($y = -110$), this is written:

$$N_M(\mathrm{re}\ M_0) = -110\ \mathrm{dB}\,.$$

The level difference ΔL for gain G is:

$$\Delta L_G = z\ \mathrm{dB}\,.$$

In this example there is no reference value because the gain G is equal to the ratio $\left(\frac{P_1}{P_2}\right)^{1/2}$ where P_1 and P_2 are power quantities of the same kind (their dimensions and units cancel). For example, if the pre-amplifier gain ($G_{\mathrm{pA},V}$), is equal to 10 V/V, the corresponding sensitivity level is 20 dB ($z = 20$), which is written:

$$\Delta L_G = 20\ \mathrm{dB}\,.$$

In Style 1, no suffix, subscript, or qualifier of any kind follows the unit symbol ‘dB’.

7.2.2. Style 2 (“dB re <reference value>”)

An alternative style (Style 2) takes the form UA-R:

$$L_E = 140\ \mathrm{dB\ re}\ E_0$$

$$N_M = -110\ \mathrm{dB\ re}\ M_0^2$$

$$\Delta L_G = 20\ \mathrm{dB}\,.$$

In Style 2, no suffix, subscript, or qualifier follows the unit symbol ‘dB’ except a qualifier of the form ‘$\mathrm{re}\ P_0$’ in the case of a level or a sensitivity level, where P_0 is the reference value of the corresponding power quantity.

Although not compliant with IEC (2002), this format is unambiguous and in widespread use. It is also the format preferred by ANSI (R2016), with the “re” in “dB re” an abbreviation of “with reference to”.

7.2.3. Style 3 (“dB (<reference value>)”)

IEC (2002) permits an alternative style (Style 3), of the form:

$$L_E = 140\ \mathrm{dB}\ (E_0)$$

$$N_M = -110\ \mathrm{dB}\ (M_0^2)$$

$$\Delta L_G = 20\ \mathrm{dB}\,.$$

In Style 3, no suffix, subscript, or qualifier follows the unit symbol ‘dB’ except the reference value in the form ‘(P_0)’ in the case of a level or a sensitivity level, where P_0 is the reference value of the corresponding power quantity.

7.3. Summary

Styles 1 to 3 are summarized in Table 24.

Table 24. Summary table: Sensitivity level and system gain versus frequency: $E_0 = 1\ \mu\mathrm{Pa}^2\mathrm{s}$; $M_0 = 1\ \mathrm{V}/\mu\mathrm{Pa}$.

What	Style 1 (Level modifier)	Style 2 (“dB re <reference value>”)	Style 3 (“dB (<reference value>”))
Level (L)	$L_E(\mathrm{re}\ 1\ \mu\mathrm{Pa}^2\mathrm{s}) =$ $140\ \mathrm{dB}$	$L_E =$ $140\ \mathrm{dB\ re}\ 1\ \mu\mathrm{Pa}^2\mathrm{s}$	$L_E =$ $140\ \mathrm{dB}\ (1\ \mu\mathrm{Pa}^2\mathrm{s})$
Sensitivity level (N)	$N_M(\mathrm{re}\ 1\ \mathrm{V}^2\ \mu\mathrm{Pa}^{-2}) =$ $-110\ \mathrm{dB}$	$N_M =$ $-110\ \mathrm{dB\ re}\ 1\ \mathrm{V}^2\ \mu\mathrm{Pa}^{-2}$	$N_M =$ $-110\ \mathrm{dB}\ (1\ \mathrm{V}^2\ \mu\mathrm{Pa}^{-2})$
Level difference (ΔL)	$\Delta L_G =$ $20\ \mathrm{dB}$	$\Delta L_G =$ $20\ \mathrm{dB}$	$\Delta L_G =$ $20\ \mathrm{dB}$

No subscripts shall be used with the unit symbol (dB, not $\mathrm{dB_{rms}}$).

No suffixes shall be used following the unit symbol dB except (with Style 2 only) of the form "re P_0", where P_0 represents the international standard reference value of the power quantity.

7.4. Reporting Levels in a Table

Any one of the same three styles may be used for reporting levels in tables.

7.4.1. Style 1 (Level Modifier)

In Style 1, levels shall be tabulated in the form illustrated by Table 25 (example showing SEL versus distance), and Table 26 (example showing sensitivity level and pre-amplifier gain versus frequency).

Table 25. Example 1 (Style 3): Sound exposure level versus distance.

x	L_E (re 1 $\mu\mathrm{Pa^2 s}$)
10 m	160 dB
100 m	140 dB
1000 m	120 dB

Table 26. Example 2 (Style 3): Sensitivity level and pre-amplifier gain versus frequency.

f	N_M (re 1 $\mathrm{V^2\ \mu Pa^{-2}}$)	ΔL_G
10 kHz	−115 dB	24 dB
100 kHz	−110 dB	20 dB
1000 kHz	−112 dB	28 dB

7.4.2. Style 2 ("dB re <reference value>")

In Style 2, levels shall be tabulated in the form illustrated by Table 27 (example showing SEL versus distance), and Table 28 (example showing sensitivity level and pre-amplifier gain versus frequency).

Table 27. Example 1 (Style 2): Sound exposure level versus distance.

x (m)	L_E (dB re 1 $\mu\mathrm{Pa^2 s}$)
10	160
100	140
1000	120

Table 28. Example 2 (Style 2): Sensitivity level and pre-amplifier gain versus frequency.

f (kHz)	N_M (dB re 1 V^2 μPa^{-2})	ΔL_G (dB)
10	−115	24
100	−110	20
1000	−115	28

7.4.3. Style 3 (“dB (<reference value>”))

In Style 3, levels shall be tabulated in the form illustrated by Table 29 (example showing SEL versus distance), and Table 30 (example showing sensitivity level and pre-amplifier gain versus frequency).

Table 29. Example 1 (Style 3): Sound exposure level versus distance.

x / m	L_E / dB (1 μPa^{2}s)
10	160
100	140
1000	120

Table 30. Example 2 (Style 3): Sensitivity level and pre-amplifier gain versus frequency.

f / kHz	N_M / dB (1 V^2 μPa^{-2})	ΔL_G / dB
10	−115	24
100	−110	20
1000	−112	28

7.5. Deprecation of dB$_X$, dB X, and dBX

Subscripts of the form dB$_X$ (e.g., dB$_{rms}$, dB$_{peak}$, dB$_{SPL}$, dB$_{SEL}$, dB$_M$, dB$_{ht}$) are deprecated.

Suffixes of the form dB X (e.g., “dB rms”, “dB peak”, “dB M”, “dB ht”) are deprecated. Where intended as modifiers to the unit symbol, suffixes of the form “dB SPL” and “dB SEL” are also deprecated. However, in the same way as “a height of 10 m” may be abbreviated as “a 10 m height”, “a sound pressure level of 140 dB” may be abbreviated as “a 140 dB SPL”, and similarly for SEL.

Suffixes of the form dBX (e.g., “dBrms”, “dBpeak”, “dBSPL”, “dBSEL”, “dBM”, “dBht”, “dBFS”, “dBc”) are deprecated.

7.6. Use of Abbreviations in Equations

With the exception of “SNR” as an abbreviation of “signal-to-noise ratio”, symbols (not abbreviations) shall be used to represent quantities and units in equations.

Literature Cited

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Appendix A. Non-acoustical Terminology (Normative)

In general the International System of Quantities (ISQ), as described in ISO/IEC (2009), shall be followed. If by exception a need arises to use a unit outside the ISQ,(e.g., for a conversion from liters to cubic inches to characterize the volume of an airgun array, IEEE (STD-260.1-2004) shall be followed. For non-acoustical terminology, the following standards are followed, in order of decreasing precedence:

- Non-acoustical ADEON terminology (this appendix)
- The JIP terminology standard Ainslie et al. (2018a)
- ISO/IEC 80000 Quantities and Units (IOS and IEC 2009)
- The International System of Units (SI): 9th edition (BIPM 2019)

Units of distance, speed and angle are listed in (Table A-1), followed by units of time in Table A-2. Units of data storage are listed in Table A-3. Data processing levels are defined in Table A-4.

Table A-1. Units of distance, speed, and angle (from ISO 2006)

Name of unit	Symbol	Definition
nautical mile	nmi	1852 m
knot	kn	1 nmi/h
degree (angle)	°	(2π/360) rad
minute (angle)	′	(1/60)°
second (angle)	″	(1/60)′

Table A-2. Units of time (see Ainslie et al. 2018b).

Unit	Symbol	Definition	Duration	Notes
second	s	duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom	1 s	SI base unit (BIMP 2019)
minute	min	60 s	60 s	Exact (BIMP 2019)
hour	h	60 min	60 min	Exact (BIMP 2019) 60 min = 3600 s
day	d	24 h	24 h	Exact (BIMP 2019) 24 h = 86 400 s
UTC month	mo	one calendar month	28 d to 31 d	
UTC year	a	one calendar year	365 d or 366 d	

Table A-3. Units of data storage. (IEC 2008).

Name of unit	Symbol	Definition	Notes
Byte	B	8 bit	The symbol B is reserved for byte (not bel) The symbol dB is reserved for decibel (not decibyte)
kilobyte	kB	1000 B	Not 1024 B
megabyte	MB	1000 kB	Not 1024 kB
gigabyte	GB	1000 MB	Not 1024 MB
terabyte	TB	1000 GB	Not 1024 GB
petabyte	PB	1000 TB	Not 1024 TB
exabyte	EB	1000 PB	Not 1024 PB
zettabyte	ZB	1000 EB	Not 1024 EB
yottabyte	YB	1000 ZB	Not 1024 ZB

Table A-4. Specification of ADEON data processing levels.

Level	Description of processing	Examples
0	Raw uncalibrated data	Binary AZFP files and .wav files before the calibration information is applied
1	Calibrated times series data	Data processed using Echoview software, after calibration is applied (Sv); sound pressure on a stationary or moving platform
2	The first level of processed data from the calibrated data. Only quantitative (temporal or spatial) processing.	Decidecade levels; SEL; depth-integrated Sv; beamformed data (individual sensors on an array are treated as if they were at one single location or site)
3	Second order processing, including some qualitative information	Whale or ship detections; products related to classification of signals; products related to signal localization
4	Interpolated products	Density estimation
5	Synthesized products related to soundscape models/maps and predictive habitat modelling (requires additional information, e.g., AIS, source model)	