
**Underwater acoustics — Quantities
and procedures for description and
measurement of underwater sound
from ships —**

**Part 1:
Requirements for precision
measurements in deep water used for
comparison purposes**

*Acoustique sous-marine — Grandeurs et modes de description et de
mesurage de l'acoustique sous-marine des navires —*

*Partie 1: Exigences pour les mesurages en eau profonde utilisées pour
des besoins de comparaison*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

The committee responsible for this document is ISO/TC 43, *Acoustics*, Subcommittee SC 3, *Underwater acoustics*.

This first edition cancels and replaces ISO/PAS 17208-1:2012, which has been technically revised.

ISO 17208 consists of the following parts, under the general title *Underwater acoustics — Quantities and procedures for description and measurement of underwater sound from ships*:

— *Part 1: Requirements for precision measurements in deep water used for comparison purposes*

The following part is under preparation:

— *Part 2: Determination of source levels*

A third part on measurement of radiated noise levels in shallow water is planned.

Introduction

This part of ISO 17208 was developed to provide a standardized measurement method for the quantification and qualification of a ship's underwater radiated noise level. This procedure measures a sector average for a certain beam aspect. It promotes the consistency of reported sound measurements from shipping sources. This part of ISO 17208 provides users with the necessary procedure to compare a ship's radiated noise level to criteria established by others or to contract specifications.

Reduction of all types of ship emissions, most notably ballast water and engine emissions, became an issue in the decade prior to publication of ISO/PAS 17208-1:2012. ISO/PAS 17208-1:2012 was developed in response to growing international concerns about underwater noise and its impact on marine animals.

Excessive underwater noise has the potential to interfere with a marine animal's ability to perform a variety of critical life functions, including navigation, communication and finding food. Because of this, the environmental impact statements of underwater projects such as pile driving, pipe laying and oil exploration now include assessments of underwater noise impact.

This part of ISO 17208 converts the PAS to an International Standard and limits its focus to a precision grade of measurement.

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Underwater acoustics — Quantities and procedures for description and measurement of underwater sound from ships —

Part 1:

Requirements for precision measurements in deep water used for comparison purposes

1 Scope

This part of ISO 17208 specifies the general measurement system, procedure, and methodology used for the measurement of underwater sound from ships under a prescribed operating condition. It does not specify or provide guidance on underwater noise criteria or address the potential effects of noise on marine organisms.

The resulting quantities are based on the root-mean-square sound pressure levels (SPL), herein used synonymously with sound pressure level or SPL measured in the far field of the ship and normalized to a distance of 1 m and reported in one-third octave bands (see 4.3). In this part of ISO 17208, the result of these measurements is called “radiated noise level”. The underwater sound pressure level measurement is performed in the geometric far field and then adjusted to the 1 m normalized distance for use in comparison with appropriate underwater noise criteria.

This part of ISO 17208 is applicable to any and all underway surface vessels, either manned or unmanned. It is not applicable to submerged vessels or to aircraft. The method has no inherent limitation on minimum or maximum ship size. It is limited to ships transiting at speeds no greater than 50 kn (25,7 m/s).

The measurement method smooths the variability caused by Lloyd’s mirror surface image coherence effects, but does not exclude a possible influence of propagation effects like bottom reflections, refraction and absorption. No specific computational adjustments for these effects are provided in this part of ISO 17208. A specific ocean location is not required to use this part of ISO 17208, but the requirements for an ocean test site are provided.

The intended uses of the method described in this part of ISO 17208 are: to show compliance with contract requirements or criteria, for comparison of one ship to another ship, to enable periodic signature assessments, and for research and development. The intended users include government agencies, research vessel operators, and commercial ship owners.

Additional post-processing would be required to use the data obtained from this measurement method for determination of the ship source levels to perform far field noise predictions such as needed for most environmental impact studies or for creating underwater noise contour maps.

2 Normative references

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

ISO 18405:—¹⁾, *Underwater acoustics — Terminology*

1) To be published.

IEC 60565, *Underwater acoustics — Hydrophones — Calibration in the frequency range 0,01 Hz to 1 MHz*

IEC 61260, *Electroacoustics — Octave-band and fractional-octave-band filters*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18405 and the following apply.

3.1

background noise

noise from all sources (biotic and abiotic) other than the ship being measured, including self noise

Note 1 to entry: See [6.2](#) for background noise adjustments.

[SOURCE: ISO 11202:2010, 3.17, modified – in the definition, added “(biotic and abiotic)” and changed “source under test” to “ship being measured”.]

3.2

beam aspect

direction to either side of the ship under test perpendicular to the vertical plane through the middle of the ship from front to back

Note 1 to entry: Beam aspect refers to the location of the hydrophone(s) with respect to the ship under test and is typically referred to as port or starboard directions. Another approach for hydrophone measurement (not applied here) is *keel aspect* where the hydrophone(s) are below the keel of the ship under test.

3.3

closest point of approach

CPA

point where the horizontal distance (during a test run) from the ship reference point of the ship under test to the hydrophone(s) is the smallest

Note 1 to entry: The distance to the hydrophone at the closest point of approach is defined by the symbol d_{CPA} as used in Formula (1).

3.4

commence exercise

COMEX

start test range location

position of the ship reference point of the ship under test at least twice (2x) the distance of the “start data” location ahead of the closest point of approach

Note 1 to entry: See [Figure 3](#).

3.5

data window angle

angle subtended at the hydrophone, between the start data location and the end data location

Note 1 to entry: The data window angle is expressed as a value in degrees as shown in [Figure 3](#).

Note 2 to entry: The data window angle is $\pm 30^\circ$.

3.6

data window length

DWL

l_{DW}

distance between the start data location and end data location

Note 1 to entry: The DWL is defined by the distance at closest point of approach and the data window angle of $\pm 30^\circ$ as given in Formula (1) and shown in [Figure 3](#).

3.7 data window period DWP

t_{DWP}

time it takes the ship under test to travel the data window length at a certain speed

Note 1 to entry: See Formula (2) and [Figure 3](#).

3.8 end data location

position of the ship reference point of the ship under test where data recording is ended

Note 1 to entry: End data location is one data window length after the start data location. See [Figure 3](#).

3.9 field calibration

method of using known inputs, possibly using physical stimuli (such as a known, calibrated and traceable acoustic or vibration source) or electrical input (charge or voltage signal injection) at the input (or other stage) of a measurement system in order to ascertain that the system is, in fact, responding properly (i.e. within the system's stated uncertainty) to the known stimulus

3.10 finish exercise FINEX end test range location

position of the ship reference point of the ship under test twice (2x) the distance to the "start data" location past the closest point of approach

Note 1 to entry: See [Figure 3](#).

3.11 frequency response

frequency range a system is able to measure, for a given uncertainty and repeatability, from the lowest frequency to the highest stated frequency

3.12 geometric far field

horizontal distance from the ship under test at which the assumption of source co-location causes less than 1 dB difference between the actual measurement and the hypothetical result when adjusting to the reference far field distance

Note 1 to entry: The definition for *acoustic far field* in ISO 18405 also applies.

3.13 hydrophone cable drift angle

angle between the vertical axis and the line created between the fixed support of the hydrophone cable and the hydrophone

3.14 insert voltage calibration

known, calibrated and traceable input stimulus in the form of an electrical input injected at the input (or other stage) of a measurement system in order to ascertain that the system is, in fact, responding properly (i.e. within the system's stated uncertainty and repeatability) to a known stimulus

3.15 Lloyd's mirror surface image coherence effects

alteration of radiated noise levels caused by the presence of a free (pressure release) surface

Note 1 to entry: Radiation from the surface image constructively and destructively influences the source's direct radiation. For this part of ISO 17208, these effects are considered as part of the source's radiation, causing it to exhibit a vertical directivity and necessitating the acquisition angle(s) is defined.

Note 2 to entry: Lloyd's mirror effects are reduced but not removed from the final radiated noise level determined herein.

3.16

measurement repeatability

expected dispersion of radiated noise levels resulting from successive measurements on the same ship at the same operating condition, carried out under the same conditions of measurement with the same equipment at the same location

Note 1 to entry: Measurement repeatability is stated in decibels and in one-third octave bands.

3.17

measurement system

data acquisition system consisting of, but not limited to, one or more transducer(s), conditioning amplifier(s), analogue-to-digital converter(s), digital signal processing computer and ancillary peripherals

3.18

measurement uncertainty

expected dispersion of the measured radiated noise level values

Note 1 to entry: Measurement uncertainty is stated in decibels for one-third octave bands using a given measurement method (averaging time, bandwidth-time product, etc.).

Note 2 to entry: See [Clause 7](#).

3.19

omni-directional hydrophone

underwater sound pressure transducer that responds nearly equally to sound from all directions with a variation in sensitivity with horizontal direction not exceeding ± 2 dB within the frequency range of the measurements.

3.20

overall ship length

longitudinal distance between the forward-most and aft-most part of a ship

3.21

radiated noise level

RNL

L_{RN}

level of the product of the distance from a ship reference point of a sound source, d , and the far field root-mean-square sound pressure, $p_{rms}(d)$, at that distance for a specified reference value

Note 1 to entry: $L_{RN} = 20 \log_{10} (p_{rms}/p_0) \text{ dB} + 20 \log_{10} (d/d_0) \text{ dB}$.

Note 2 to entry: Radiated noise level is expressed in decibels (dB).

Note 3 to entry: The reference value for sound pressure (p_0) is $1 \mu\text{Pa}$. The reference value for distance (d_0) is 1 m. The combined RNL reference value is $p_0 d_0$ is $1 \mu\text{Pa}\cdot\text{m}$.

Note 4 to entry: The resulting level is denoted "LRN, dB re $1 \mu\text{Pa}\cdot\text{m}$ ". This designation replaces the past use of "Lp, dB re $1 \mu\text{Pa}$ @ 1 m".

Note 5 to entry: RNL varies in both horizontal and vertical aspect in the far field. This procedure determines an azimuthal sector averaged about the hydrophone position; and vertical-elevation averaged quantity in the beam aspect about the ship reference point.

3.22**root-mean-square sound pressure level
sound pressure level****SPL** L_p

for a specified reference value, p_0 , the level of the root-mean-square sound pressure, p_{rms}

Note 1 to entry: In formula form, $L_p = 20 \log_{10}(p_{\text{rms}}/p_0)$ dB, where p_{rms} is the root-mean-square sound pressure.

Note 2 to entry: Root-mean-square sound pressure level is expressed in decibels (dB).

Note 3 to entry: In underwater acoustics, the reference value of root-mean-square sound pressure, p_0 , is 1 μPa .

Note 4 to entry: Frequency weighting and time weighting, as applicable, shall be specified.

Note 5 to entry: Root-mean-square sound pressure is a field quantity (see ISO 80000-3:2006, Clause 3 and ISO 80000-1:2009, Annex C).

Note 6 to entry: The abbreviations “RMS SPL” and “root-mean-square SPL” are deprecated because in normal use of English, these would mean “root-mean-square value of SPL”, which means something different from “level of the root-mean-square sound pressure”.

3.23**ship reference point**

point on the ship from which the distances are defined

Note 1 to entry: For the purpose of this part of ISO 17208, the ship reference point is located transversely at the ship centreline, longitudinally a quarter-length forward of the stern and vertically at the height of the sea surface.

Note 2 to entry: The location for the ship reference point applies for all frequencies.

Note 3 to entry: The ship reference point may also serve as an approximate location for the ship's acoustic centre.

3.24**slant range**

distance from the ship reference point of the ship under test to each hydrophone

3.25**sound speed profile**

measure of the speed of sound in seawater as a function of depth, measured vertically through the water column

3.26**start data location**

position of the ship reference point of the ship under test where data recording is started

Note 1 to entry: See [Figure 3](#).

3.27**test site**

location where the underwater noise measurements are performed

4 Instrumentation

4.1 General

In order to quantify the underwater sound from a ship, three main instrumentation components are required: (1) hydrophone and signal conditioning, (2) data acquisition, recording, processing and display system, and (3) distance measurement system. Detailed specifications of each of the measurement systems are given below. A summary of the parameters is given in [Table 1](#).

Table 1 — Summary of measurement parameters

Measurement parameter	Value/Quantity
Achievable expanded measurement uncertainty (expressed as the typical value for applicable one-third octave bands)	5 dB (10 Hz to 100 Hz one-third octave bands) 3 dB (125 Hz to 16 000 Hz one-third octave bands) 4 dB ($\geq 20\,000$ Hz one-third octave bands)
Measurement repeatability (expressed as the typical value for applicable one-third octave bands)	3 dB (10 Hz to 100 Hz one-third octave bands) 1 dB (125 Hz to 16 000 Hz one-third octave bands) 1 dB ($\geq 20\,000$ Hz one-third octave bands)
Bandwidth	One-third octave band
Frequency range, lower one-third octave band	10 Hz
Frequency range, upper one-third octave band	20 000 Hz (minimum) but up to 50 000 Hz as may be required by the criteria (see 4.3)
Number of hydrophones	Three
Hydrophone geometry	See Figure 1
Nominal hydrophone angles	15°, 30°, 45° angle
Minimum water depth	Greater of 150 m or 1,5× overall ship length
Nominal distance at closest point of approach (CPA)	Greater of 100 m or 1× overall ship length
Tolerance of the actual distance at CPA	-10 % to +25 %
Distance ranging measurement uncertainty (at CPA)	≤ 10 %
Data window angle ($\pm$ CPA)	$\pm 30^\circ$
Data window length, metres	Determined using Formula (1) Shown in Figure 3
Data window time, seconds	Determined Using Formula (2) Shown in Figure 3
Data window averaging time	One overall sample equal to DWP
Minimum number of runs per ship condition	4 Total 2 Port 2 Starboard
Recommended weather/sea conditions	Wind speed ≤ 20 kn (see 5.3)
Portable hydrophone calibration	Laboratory calibration every 12 months Field calibration, as below, daily during measurements
Fixed hydrophone calibration	Laboratory calibration prior to installation Confirmation using calibrated sound source or reference hydrophone every 12 months Field calibration, as below, daily during measurements
System field calibration	Insert voltage calibration
Auxiliary measurements	Shaft speed, wind speed and direction (see Clause 8 for other measurements)

4.2 Hydrophone and signal conditioning

For the purposes of this part of ISO 17208, the terms hydrophone, underwater electro-acoustic transducer, or underwater microphone may be used synonymously. Here, the term hydrophone is used and includes any signal conditioning electronics either within or exterior to the hydrophone. The hydrophone(s) shall have the sensitivity, bandwidth and dynamic range necessary to measure the ship under test and meet the performance parameters given in [Table 1](#).

This part of ISO 17208 requires three hydrophones that should be omni-directional across the required frequency range of 10 Hz to 20 000 Hz, or higher if required, see [Table 1](#). Directional hydrophones may be used, as long as the directional characteristics are accounted for in the post-processing (see [6.3](#)). The hydrophones may or may not have integral cable. However, the required performance shall be obtained with the full cable length to be used during the test.

When portable hydrophones are used, they shall be laboratory calibrated every 12 months in accordance with IEC 60565 for all required one-third octave bands. When fixed (i.e. permanently installed underwater) hydrophones are used, they shall be laboratory calibrated before installation in accordance with IEC 60565 for all required one-third octave bands. The fixed hydrophone calibration shall be confirmed by a comparative measurement utilizing a calibrated underwater sound source every 12 months. Alternatively, the fixed hydrophones and associated cabling may be lifted from the water every 12 months for maintenance and the hydrophones laboratory calibrated.

The sensitivity and directivity of the hydrophones shall be determined to within ± 2 dB.

4.3 Data acquisition, recording, processing and display

The data acquisition, recording, processing and display system shall be capable of accurately acquiring, recording, processing and displaying data from the hydrophones. Such systems may comprise tape recorders, computer-based data acquisition systems or hardware-specific devices (such as spectrum analysers) or combinations of these. The data acquisition system should have an appropriate sampling rate and anti-aliasing filters following Nyquist requirements and appropriate dynamic range for either analogue or digital systems. All frequency-domain averaging shall be linear with sampling consistent with the data window period (DWP), see [6.1](#).

The time domain signal from each hydrophone shall be acquired and recorded simultaneously and be sample-accurate for all three channels. Tracking and time stamp data (see [4.4](#)) shall be recorded synchronously with the acoustic data to enable reconstruction of the track and data processing.

The broadband processing shall cover the one-third octave bands from 10 Hz to 20 000 Hz in accordance with IEC 61260, Base 2 (true one-third octaves) or Base 10 (as also called decidecade in ISO 18405), Class 1. Throughout this International Standard, the use of the term one-third octave can be considered equivalent to the term decidecade. If required by a ship's noise criteria specification (i.e. ICES CRR-209), one-third octave band processing up to 50 000 Hz may be necessary.

4.4 Distance measurement

Distance measurement is required to continuously determine the actual distance between the hydrophones and the ship reference point of the ship under test.

For measurement with surface-suspended hydrophones, the distance measurement systems shall determine the horizontal distance from the sea surface position above the hydrophone(s) (i.e. the device or buoy used to suspend the cable) to the ship reference point of the ship under test. The distance measurement device may utilize any method (e.g. optical, acoustical, GPS, radar) to achieve the required accuracy.

For measurement with bottom-suspended hydrophones, the distance measurement systems shall determine the horizontal distance from the sea surface position above the hydrophone(s) (corresponding to the point of attachment of the cable on sea bottom) to the ship reference point of the ship under test.

For both types of hydrophones, the distance measurement system shall be accurate to $\leq 10\%$ of the distance at CPA. The slant range from the ship under test to the hydrophone(s) may be computed during post-processing of the data in accordance with 6.4. It is not necessary to take into account any drift that the hydrophones could experience after they are deployed, provided the hydrophone cable drift does not exceed 5° . If the drift angle does exceed 5° , then it shall either be reduced or the drift angle shall be taken into account when determining the slant range.

The hydrophone cable drift angle may be estimated by the use of a depth gauge that indicates the depth of the hydrophones. If the drift angle is believed to exceed 5° , it can be reduced by attaching a weight to the end of the hydrophone cable or using a larger buoy for bottom-suspended configurations. Use of a larger buoy (or buoy of greater buoyancy) may increase the drag on the buoy and thus increase the strum frequencies. Drift angles are usually smaller for free-floating suspensions that do not use a data transmission cable (e.g. an acoustic or electromagnetic data link). The uncertainty of the estimated slant range between the hydrophones and the ship reference point shall not exceed 10% .

Other means than the cable drift angle can be used to determine accurately the actual distance between the hydrophones and the ship reference point of the ship under test (e.g. use of Doppler effect on a known single frequency signal emitted from the hull, or the use of acoustic transponders or pinger systems).

5 Measurement requirements and procedure

5.1 General

In order to perform an accurate measurement of a ship's underwater sound, several factors shall be addressed correctly, e.g. selection of an appropriate test site, proper deployment of hydrophones and proper operation of the ship under test. These factors are given below.

5.2 Test site requirements

The minimum water depth shall be 150 m or one and one-half times ($1,5x$) the overall ship length, whichever is greater.

The measurement test site need not use a specific ocean location. It is up to the test organization and the ship owner's representative (ship owner, shipyard, etc.) to determine the suitability of the proposed test site for the intended measurements. Other factors to consider are background noise, ship traffic, oceanography, bottom type, local weather, ship manoeuvrability and safety.

The background noise should be low enough to permit measurement of the underwater sound of the ship under test over the frequency range of interest. Where the background noise limits the measurements, corrections shall be applied (see 6.2).

There are circumstances where the problem of background noise limiting the measurable frequencies is insurmountable. In such cases where measured levels are background-limited and no correction is possible (see 6.2), these data shall either be designated as background-limited or not presented.

5.3 Sea surface conditions

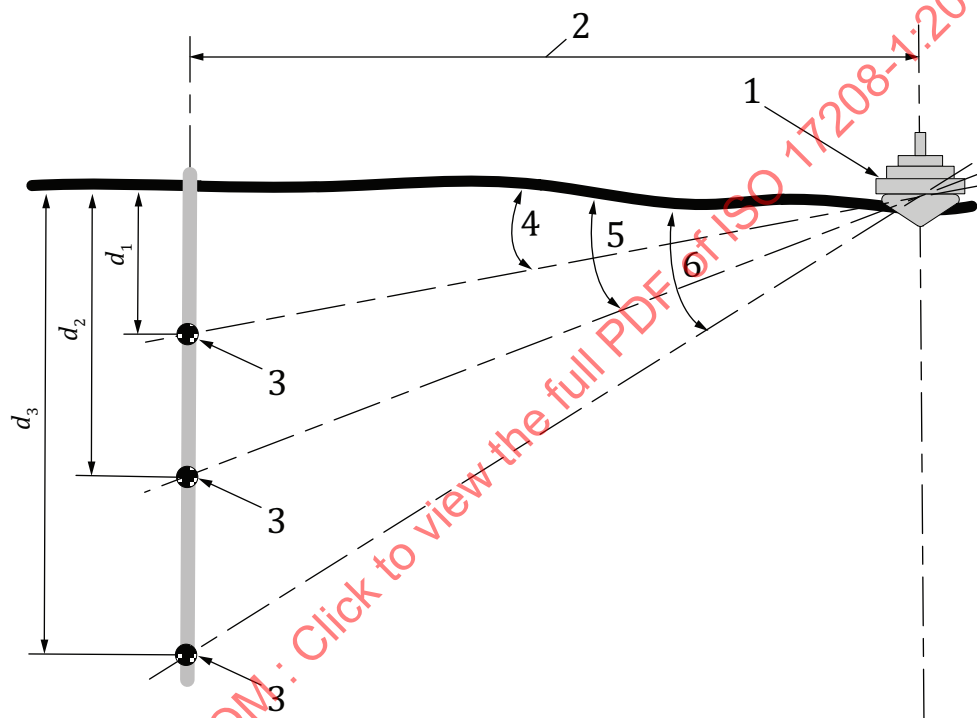
The sea surface conditions during testing are of concern, since rough seas may add background noise and cause instability of the ship under test and its propulsion system. For example, rougher surface conditions can increase the background noise in the water as well as contribute to measurement array excitation thereby creating limitations because of signal-to-noise adjustments (see 6.2). Of concern in this respect is the repeatability of the surface ship's radiated noise level in various sea surface conditions. For example, wave heights can cause the propulsor to come out of the water causing significant radiated noise level differences between low vs. high surface wave conditions.

The limiting surface conditions affecting the radiated noise levels are a function of numerous variables (wave height, period, direction relative to ship course, ship seakeeping characteristics, source depth,

etc.). As a generality, smaller length ships require lower wave heights to attain consistent radiated noise level measurements. The recommended wind speed limitation of ≤ 20 kn (10,28 m/s) provides a nominal value for ships greater than 100 m. Smaller ships could require more benign surface conditions while larger ships can tolerate rougher surface conditions.

5.4 Hydrophone deployment

The hydrophones shall be located so as to measure the beam aspect of the ship under test. The three hydrophones shall be positioned vertically in the water column at depths that result from nominal 15° , 30° and 45° angles from the sea surface at a distance equal to the nominal distance at CPA (Figure 1). The hydrophone deployment method should ensure that any dip in the hydrophone's directivity should be such that the orientation of the hydrophone is directed towards the seabed.



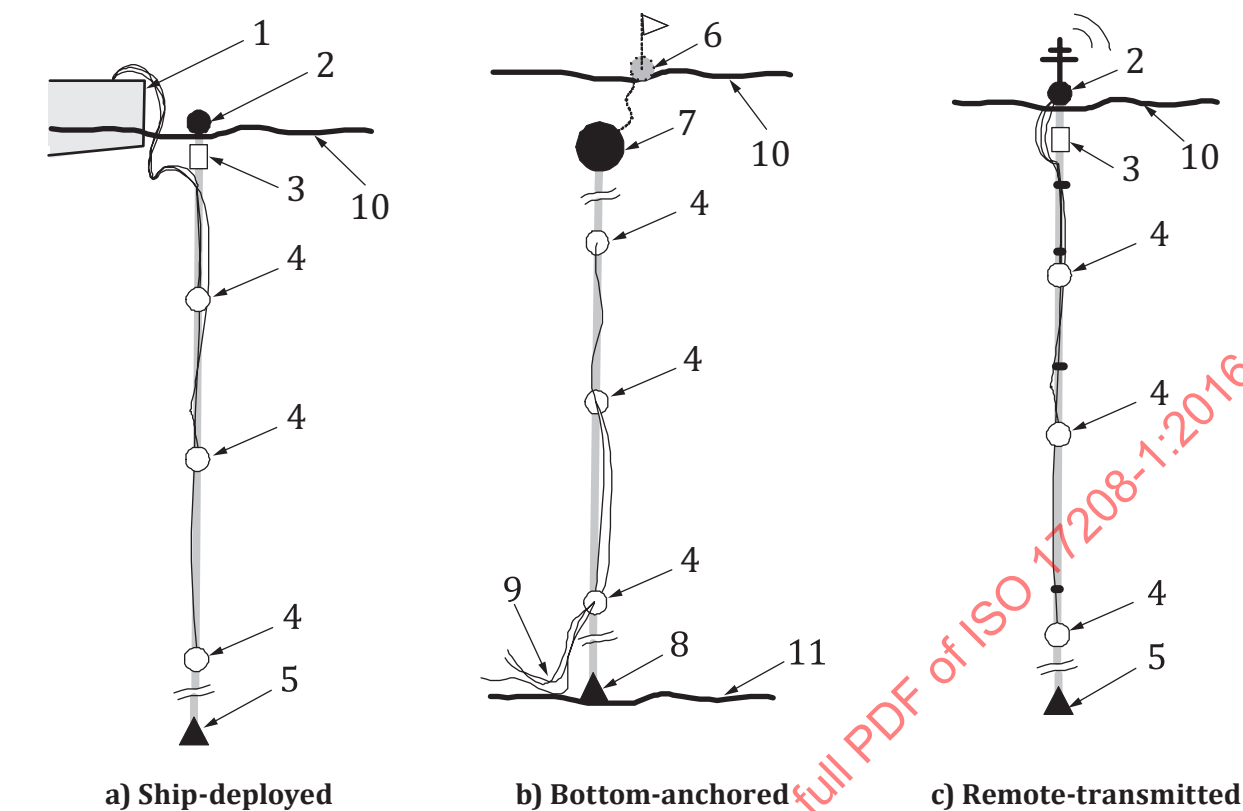
Key

1	ship under test	d_1	$d_{CPA} \tan(15^\circ)$
2	distance, d_{CPA} , at closest point of approach	d_2	$d_{CPA} \tan(30^\circ)$
3	hydrophone	d_3	$d_{CPA} \tan(45^\circ)$
4	15° angle between surface and shallowest hydrophone		
5	30° angle between surface and middle hydrophone		
6	45° angle between surface and deepest hydrophone		

NOTE $d_{CPA} = 100$ m or one overall ship length, whichever is the greater.

Figure 1 — Hydrophone geometry

Provisions shall be made to mitigate the effects of cable strum and sea surface effects on the measurements. Figure 2 shows potential deployment approaches, but other solutions are allowed as long as the physical locations of Figure 1 and requirements with respect to the measurement uncertainty are fulfilled.



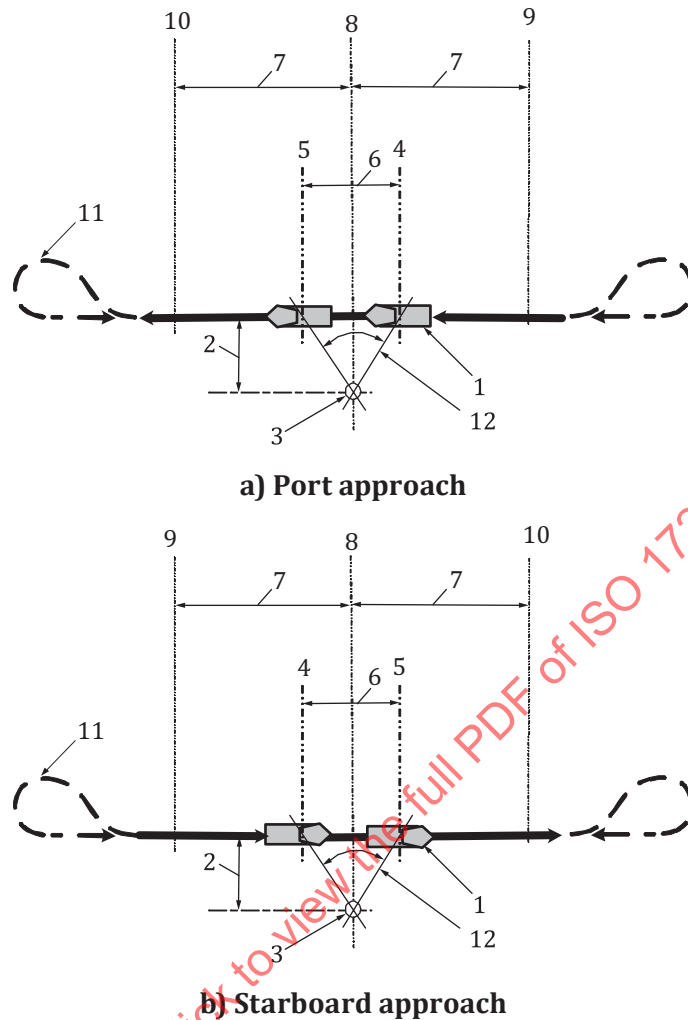
Key	
1	support vessel
2	surface buoy
3	suspension device
4	hydrophone
5	weight
6	surface buoy (optional)
7	subsurface buoy
8	bottom anchor
9	signal lines to shore
10	ocean surface
11	ocean bottom

NOTE Figure not to scale. See 5.2 and 5.4 for hydrophone arrangement details.

Figure 2 — Typical hydrophone deployment configurations

5.5 Test course and ship operation

The run configuration is shown in Figure 3. The ship under test shall transit a straight line course to achieve the required distance at CPA. The starting point of the run (or the COMEX) is at least twice the data window length (DWL) before the CPA. The ending point of the run (or the FINEX) is at least twice the DWL after CPA. At COMEX, the ship under test shall have achieved the required run conditions. Unless otherwise required by the ship’s test plan, the ship under test shall maintain constant speed, fixed machinery conditions and minimum use of helm to maintain course through FINEX.

**Key**

1	ship under test	7	$2 \times \text{DWL}$
2	distance, dCPA, at closest point of approach (CPA)	8	CPA point
3	hydrophone(s)	9	COMEX
4	start data	10	FINEX
5	end data	11	Williamson curve
6	DWL	12	$\pm 30^\circ$ (total = 60°)

NOTE 1 $l_{\text{DW}} = 2d_{\text{CPA}} \tan(30^\circ)$, where $d_{\text{CPA}} = 100 \text{ m}$ or one overall ship length, whichever is the greater.

NOTE 2 $t_{\text{DWP}} = \left(\frac{l_{\text{DW}}}{v} \right)$, where v is the ship's speed, in m/s.

Figure 3 — Test course configuration, (a) port and (b) starboard approaches

5.6 Test sequence

When all aspects of the underwater noise survey are in place, steps a) through j) shall be performed for each test run. Four (4) runs comprising two (2) runs for each side of the ship (alternating port and starboard aspect) shall be performed for each ship condition to be tested.

- a) The ship captain, master or owner's representative shall confirm that the necessary propulsion machinery line-up and auxiliary machinery conditions are set as required.

- b) Acoustic test personnel operating the measurement instrumentation shall confirm all measurement systems are operational.
- c) Initially, the ship under test shall move to a position at least 2 km from the hydrophones and come to a quiet condition. All ship systems including diesel generators shall remain operating. When in position, the ship under test shall notify the acoustic test personnel. Background noise measurements may be performed at this time.
- d) When background noise measurements are completed, acoustic test personnel shall notify the ship under test to proceed toward the hydrophones at the required ship operating conditions and speed.
- e) When the ship under test reaches the start test range location (COMEX), all ship operating conditions (speed, machinery configurations) shall remain unchanged until end test range location (FINEX) is reached. See [Figure 3](#) for a diagram of the two locations.
- f) Measurement systems may be started at COMEX, but shall be started before the start data window location.
- g) The distance at CPA shall be measured and recorded.
- h) When the DWP is completed, the acoustic test personnel shall announce that the end data location has been reached. The ship under test shall continue course to the FINEX before making any changes in ship operation, direction or speed.
- i) At FINEX, the ship under test shall perform the reverse course manoeuvre shown in [Figure 3](#) so as to run back through the test range on the opposite side and repeat steps e) to h) inclusive. This process shall be repeated four times, two with starboard approaches and two with port approaches.
- j) Background noise measurements, steps c) and d), shall be taken at the beginning and end of each test period (e.g. half-day or day of measurements). If weather or traffic conditions significantly change (i.e. changes in wind greater than 5 kn [2,6 m/s], sea state, ship population, or precipitation), the survey shall be suspended and measurements shall be taken to determine background noise levels and confirm that background noise requirements are still met.

6 Post-processing

6.1 General

When the testing, as given in [Clause 5](#), has been completed, post-processing will be required to adjust sound pressure level spectra for background noise conditions and sensitivity adjustments, and to normalize the data for distance differences. The next step will be to combine multiple hydrophones and multiple runs.

The data window angle shall be $\pm 30^\circ$ from the CPA as shown in [Figure 3](#). The distance at CPA shall be the greater of 100 m or one times (1x) the overall ship length. The tolerance of the actual distance at CPA shall not be less than -10 % and no greater than +25 % (-10 %/+25 %). The measurement uncertainty of the distance at CPA shall be less than 10 % as given in [Table 1](#). The DWL (I_{DW}), in metres, is equal to the distance travelled by the ship under test within the $\pm 30^\circ$ window as given in Formula (1).

$$I_{DW} = 2d_{CPA} \tan(\theta) \quad (1)$$

where

d_{CPA} is the measured distance at the CPA for each run, in metres;

θ is equal to 30° ; $\tan(30^\circ)$ is 0,577 3.

The DWP (t_{DWP}), expressed in seconds, shall be the time to travel the data window length as a function of ship speed, as given in Formula (2).

$$t_{DWP} = \left\{ \frac{l_{DW}}{v} \right\} \quad (2)$$

where

l_{DW} is the DWL, in metres;

v is the ship speed, in metres/second. To obtain the speed in m/s, multiply speed in knots or nautical miles/hour by 0,514 44.

The DWP shall be reported as one overall sample over which the resulting radiated noise level shall be computed.

6.2 Background noise adjustments

Since unexpected changes in background noise often occur (e.g. a passing ship or a rain squall) the background noise shall be assessed as described in 5.6 c). With the ship stationary, a background measurement (at least 30 s average) is made when the ship is 2 km from the hydrophone(s). If the measured SPL needs to be modified, the adjustments are made to one-third octave data. Attempts to adjust discrete frequency (tonal) data have usually led to undesirable results and are not recommended.

A background noise data set shall be assigned to each measurement run in order to compare the measured level of the ship under test to the background noise at the approximate time of the test. The signal-plus-noise-to-noise level difference, or ΔL , is defined in Formula (3).

$$\Delta L = L_{p_{s+n}} - L_{p_n} = 10 \log_{10} \left(\frac{p_{s+n}^2}{p_n^2} \right) \text{ dB} \quad (3)$$

where

ΔL is the signal-plus-noise-to-noise level difference computed using Formula (3) for each one-third octave band;

p_{s+n} is the root-mean-square sound pressure at the hydrophone in μPa . This value includes both the desired signal and undesired background noise;

p_n is the root-mean-square sound pressure of the background noise at the hydrophone in μPa ;

$L_{p_{s+n}}$ is the root-mean-square sound pressure level in decibels with ship under test present for each run;

L_{pn} is the background root-mean-square sound pressure level with the ship under test not influencing the measurement (at 2 km from hydrophones) in dB.

If ΔL is greater than 10 dB, no adjustments are necessary. If ΔL is between 3 dB and 10 dB and if the background noise is stable (i.e. no changes in environmental conditions, sea state, vessel traffic at the site), then adjustments to the measurements are required using Formula (4). It shall be clearly identified in the report that such corrections have been applied. If ΔL is less than 3 dB then the data shall be so noted or discarded.

$$L'_p = 10 \log_{10} \left[10^{(L_{p_{s+n}}/10 \text{ dB})} - 10^{(L_{pn}/10 \text{ dB})} \right] \text{ dB} \quad (4)$$

where

L'_p is the background noise adjusted root-mean-square sound pressure level of the ship under test, computed in one-third octave bands.

Formula (4) is only used if ΔL is greater than or equal to 3 dB and less than 10 dB.

6.3 Sensitivity adjustments

Additional adjustments to the L'_p value given in 6.2 shall be made for any miscellaneous adjustments such as directivity, cable sensitivity, or amplifier gain. Sensitivity adjustments shall be made as given in Formula (5). These adjustments shall remain constant throughout the ship survey.

$$L''_p = L'_p + A_{\text{SEN}} \quad (5)$$

where

L''_p is the unweighted root-mean-square sound pressure level after background adjustment;

A_{SEN} is the adjustment for miscellaneous hydrophone sensitivities.

All sensitivity adjustments are made to one-third octave band data. Such adjustments may be measured by the user or provided by the instrumentation vendors.

NOTE L''_p is the unweighted sound pressure level. L'_p is a weighted sound pressure level, where the weighting characterizes the frequency response of the hydrophone and processing chain. This weighting is corrected for by applying a correction A_{SEN} in each one-third octave band. If the frequency response is flat in the frequency range of interest then $A_{\text{SEN}} = 0$ dB and L''_p is equal to L'_p , and both are equal to the unweighted sound pressure level.

6.4 Distance normalization

The final adjustment of the sensitivity-adjusted measured sound pressure level, L''_p , is normalization for distance. The typical distance from the moving ship to the measurement transducer is one ship length or 100 m, whichever is greater. However, because of the effects of current and seas this distance may vary by $\pm 10\%$, which is acceptable provided the distance from the hydrophones to the ship reference point is known.

Depending on measurement technology used (e.g. GPS, sonar or laser), the distance from the ship to the hydrophone may need to be computed using two separate distances: (1) horizontally from the ship reference point to the sea surface above the hydrophones; and (2) vertically from the sea surface to each hydrophone. The total distance from the ship to each hydrophone is determined using Formula (6).

$$d_{\text{Total}} = \sqrt{d_{\text{Horz}}^2 + d_{\text{Vert}}^2} \quad (6)$$

where

d_{Total} is the total distance at CPA to be used in the distance normalization Formula (7) below;

d_{Horz} is the horizontal distance from the ship reference point of the ship under test to the surface buoy supporting the hydrophones at CPA. This distance would be that determined by the distance ranging system (i.e. GPS system, sonar or laser range finder), corrections to the centreline, waterline, and ship reference point for the measured ranging value could be needed;

d_{Vert} is the depth of each hydrophone, h (h_1 represents a shallow hydrophone, h_2 a middle hydrophone and h_3 a deep hydrophone).

The underwater radiated noise level for each run and each hydrophone is determined by Formula (7).

$$L_{RN}(r, h) = L_p'' + 20 \log_{10} \left(\frac{d_{Total}}{d_{ref}} \right) \text{ dB} \quad (7)$$

where

$L_{RN}(r, h)$ is the underwater radiated noise level, as a function of run number, r , and hydrophone location h (h_1 represents a shallow hydrophone, h_2 a middle hydrophone and h_3 a deep hydrophone);

d_{Total} is the total distance from the ship under test to each hydrophone (metres); d_{ref} is the reference distance of 1 m.

This normalization assumes that the ship is a directive source at the surface (i.e. the surface image is considered as part of the source and the underwater sound pressure level is specific for the beam aspect at elevation angles between 15° and 45°).

6.5 Hydrophone and run combination post-processing

The resulting data set from measurements performed in [Clause 5](#) shall be one-third octave band radiated noise levels relative to 1 µPa m in decibels (dB) from 10 Hz to 20 000 Hz, or higher if required, see [Table 1](#). Such data sets shall be prepared for three hydrophones and for four measurement runs, two per aspect (port and starboard). The port and starboard aspect runs shall be kept separate. These multiple data sets shall be adjusted and normalized according to [6.2](#) through [6.4](#). This subclause describes how to combine the 12 data sets for each condition into one set of values in one-third octave bands.

The first step in the post-processing is to determine the power average of the radiated noise level from all three hydrophones (h_1 , h_2 and h_3) that results in the radiated noise level for each run, $L_{RN}(r)$, using Formula (8).

$$L_{RN}(r) = 10 \log_{10} \left[\frac{10^{L_{RN}(r, h_1)/10 \text{ dB}} + 10^{L_{RN}(r, h_2)/10 \text{ dB}} + 10^{L_{RN}(r, h_3)/10 \text{ dB}}}{3} \right] \text{ dB} \quad (8)$$

where

$L_{RN}(r)$ is the power-averaged underwater radiated noise level for three hydrophones for run, r ;

$L_{RN}(r, h_1)$ is the underwater radiated noise level for the shallow (h_1) hydrophone for run, r ;

$L_{RN}(r, h_2)$ is the underwater radiated noise level for the middle (h_2) hydrophone for run, r ;

$L_{RN}(r, h_3)$ is the underwater radiated noise level for the deep (h_3) hydrophone for run, r .

The k runs of data are then arithmetically averaged to determine the final sound source value for each run as given in Formula (9).

$$L_{RN} = \frac{\sum_{r=1}^{r=k} L_{RN}(r)}{k} \quad (9)$$

where

- L_{RN} is the radiated noise level for, k , runs as computed in Formula (9);
- $L_{RN}(r)$ is the power-averaged underwater radiated noise level for three hydrophones for run, r , as determined by Formula (8);
- k is the total number of runs: for $k = 4$ or 2 (for port- and starboard-only computations).

For each ship condition, L_{RN} should be determined separately for each side of the ship (i.e. port aspect and starboard aspect) and then for both sides together. L_{RN} is the resulting radiated noise level for each ship operating condition. It is a function of one-third octave bands and shall be the values that are reported, compared to limits or compared to other data sets.

7 Measurement uncertainty

The combined expanded measurement uncertainty of the resulting radiated noise level (RNL) values is given in [Table 1](#). The combined uncertainty is divided into low, mid and high frequency ranges. The uncertainty values are 5 dB for the low frequency (10 Hz to 100 Hz) one-third octave bands, 3 dB for the mid frequency (125 Hz to 16 000 Hz) one-third octave bands and 4 dB for the high frequency ($\geq 20\,000$ Hz) one-third octave bands. These values are expressed as the typical value for applicable one-third octave bands. The combined measurement uncertainty has been evaluated from a combination of components, which describe random errors and errors caused by effects that may introduce systematic bias into the measurements. The usual evaluation of uncertainty (defined in ISO/IEC Guide 98-3 as “Type A”) by a statistical analysis of a large quantity of observations is not possible for RNL measurements. The major components of RNL uncertainty are the source conditions, uncertainty in the SPL measurement and uncertainty of the RNL computation. A discussion of each follows.

Variations in the ship’s acoustic source condition will affect the repeatability and reproducibility of SPL and RNL measurements. These variations are highly case specific. Some conditions (machinery settings and propeller r/min, draught) can potentially be controlled by the use of rigorous measurement procedures. Environmental effects are mainly relevant for reproducibility, they may affect repeatability as well, for example, speed differences at courses with and against the current and due to weather variations. However, the measurement process provided in this part of ISO 17208 will compensate for such issues and repeatability of prior methods given in ANSI/ASA S12.64-2009/Part 1 has been reported at $\leq 1,0$ dB. The same level of repeatability is used for the mid and high frequency one-third octave bands and a 3 dB repeatability is used for the low frequency bands.

The SPL measurement uncertainty depends on the quality of the equipment and processing. If high quality instrumentation is used and specified calibration protocols are followed, a combined uncertainty for hydrophone sensitivity, amplifier gain and analogue-to-digital conversion is nominally 1 dB for the low and mid frequency one-third octave bands, and 3 dB for the high frequency one-third octave bands. The uncertainty in the processing (conversion to frequency spectrum) is frequency dependent and is mainly of interest for narrowband analysis or for the lowest one-third octave bands. For example, in the 10 Hz one-third octave band, the uncertainty is about 0,5 dB and all higher frequency bands would have a lower value of uncertainty. To be conservative, a 0,5 dB uncertainty has been used for all one-third octave bands.

The averaging time will affect the SPL measurement, because the distance between ship and hydrophones varies during a run. The received sound pressure will vary with time because the lengths of the direct and surface reflected sound paths vary. It can be shown that the associated uncertainty is of the order of 1 dB for all one-third octave bands or less if the track length over which the ship sails during the averaging time is smaller than the horizontal distance between ship and hydrophone at CPA.

This part of ISO 17208 requires a correction for background noise if the SPL of signal plus background noise (ΔL) is 3 dB to 10 dB larger than the SPL of the background noise, as given in [6.2](#). If ΔL is larger than 10 dB, the correction is unnecessary. If ΔL is smaller than 3 dB, the data should be discarded as the background correction will be unreliable. For the cases where the ΔL is between 3 dB to 10 dB, the uncertainty of the background correction will be compensated for resulting in 0 dB uncertainty. For the cases where the ΔL is greater than 10 dB, the uncertainty of the background correction will be no more than -0,4 dB.