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

Part 3: Requirements for measurements in shallow water

National foreword

This British Standard is the UK implementation of ISO 17208-3:2025.

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A list of organizations represented on this committee can be obtained on request to its committee manager.

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

**Part 3:
Requirements for measurements in
shallow water**

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

Partie 3: Exigences pour les mesurages en eau peu profonde

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Foreword

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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 document 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).

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This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 3, *Underwater acoustics*.

A list of all parts in the ISO 17208 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The ISO 17208 series describe procedures for the measurement and analysis of underwater sound from ships. The methodology and measurement configuration are sufficient to provide reliable acoustic data, but also suitable for end-users to conduct the measurements without access to large, fixed sound measurement facilities. ISO17208-1 covers measurements of radiated noise level in deep water, and ISO 17208-2 the calculation of source level from the deep-water data. This document has been developed to address the need to cover source level measurements in shallow water, one reason being that deep water maritime areas are sometimes far away from the zone of operation of the ships considered.

The development of this document was supported by the EU-funded Horizon 2020 research programme SATURN (Developing solutions to underwater radiated noise)¹⁾ and by the MMP2 project²⁾, sponsored by Transport Canada's Innovation Centre.

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

Part 3: Requirements for measurements in shallow water

1 Scope

ISO 17208 series describe procedures for the measurement of underwater sound radiated by the ship under test, and for calculating sound source quantities such as source level and radiated noise level from the measurement results.

In ISO 17208-1 to ISO 17208-3 it is presumed that the ship under test cooperates in the measurements, sailing multiple runs over a specified track past the measurement system at a specified speed with pre-determined machinery configurations. Opportunistic measurements of the radiated sound of passing ships are outside the scope of these three standards.

Part 1 of the ISO 17208 standards^[1] provides the procedure to quantify the underwater sound from the ship in terms of its radiated noise level, which is calculated from the sound pressure level (SPL) measured in the far field of the ship, in beam aspect, scaled by the distance to CPA and reported in decidecade bands. The intended use of radiated noise level is 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.

ISO 17208-2^[1] specifies methods for calculating the source level of an equivalent monopole source at a specified nominal source depth from the radiated noise level values obtained according to ISO 17208-1. The intended use of source level, with associated nominal source depth, is to perform far field sound predictions such as needed for environmental impact studies or for creating underwater sound contour maps.

ISO 17208-1 and ISO 17208-2^[1] are applicable for measurements in deep water, defined as water depth greater than the larger of 150 m and 1,5 times overall ship length. The allowable water depths and environmental conditions for part 3 measurements are described in [4.5](#).

This document specifies procedures for the measurement of underwater sound radiated by the ship under test in shallow water. It also specifies procedures for the calculation of source level, with associated nominal source depth, from the sound pressure measurements, accounting for the relevant phenomena that govern the propagation of sound in shallow water. These calculations are described in [Clause 7](#). Once the source level has been calculated, other metrics may be calculated from the source level and the source depth. [7.3](#) provides a procedure for calculating the radiated noise level that would have been measured in deep water according to ISO 17208-1 for the same ship with the same operating condition.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 18405, *Underwater acoustics — Terminology*

ISO 17208-1:2016, *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*

IEC 60500, *Underwater acoustics - Hydrophones - Properties of hydrophones in the frequency range 1 Hz to 500 kHz*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18405, IEC 60500 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

NOTE From ISO 18405, this includes the following terms: sound pressure, sound pressure level (SPL), propagation loss, source level, acoustic far field, decade. From IEC 60500, this includes the following terms: hydrophone, and sensitivity level.

3.1 shallow water

water of depth less than the larger of 150 m and 1,5 times the overall ship length

3.2 deep water

water of depth greater than the larger of 150 m and 1,5 times the overall ship length

3.3 overall ship length

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

3.4 acoustic ship length

L
user defined length L over which the ship is assumed to radiate the dominant sound over the frequency range of interest

Note 1 to entry: Dependent on the location of the dominant sound sources on the ship under test, this can be the overall ship length or the length of the aft part of the ship, where the propellers and the main engines are located.

3.5 ship reference point

position of the equivalent sound source representing the ship

Note 1 to entry: For the purpose of this part of ISO 17208, the ship reference point is located longitudinally at the centre of the *acoustic ship length* (3.4), transversely at the ship centre line and vertically at the nominal source depth.

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

3.6 nominal source depth

d_s
nominal depth below the sea surface of the monopole point source from which the sound is considered to originate, and equal to 0,7 times the ship's draught

Note 1 to entry: In formula form:

$$d_s = 0,7D$$

where D is the draught of the ship.

Note 2 to entry: The draught of the ship is considered to be the average of the stern and bow draughts.

Note 3 to entry: The choice of the nominal source depth is somewhat arbitrary, and the choice of 70 % of the mean draught represents a compromise. The value of the nominal source depth is to be reported alongside the equivalent monopole beam aspect source level value.

3.7 closest point of approach

CPA

point at which the horizontal distance (during a test run) from the ship reference point of the ship under test to the hydrophone(s) reaches its minimum value

3.8 closest point of approach distance

CPA distance

d_{CPA}

horizontal distance (during a test run) from the ship reference point of the ship under test to the hydrophone(s) at its closest point of approach

3.9 beam aspect

aspect normal to ship centre line from bow to stern

Note 1 to entry: Beam aspect refers to the location of the hydrophone (s) with respect to the ship under test in port or starboard direction. For the purpose of ISO 17208, the beam aspect is measured over $\pm 30^\circ$ data window angles.

3.10 data window angle

horizontal 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 1](#).

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

3.11 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 [Figure 1](#). In formula form:

$$l_{DW} = 2 \tan(30^\circ) d_{CPA}$$

where d_{CPA} is the CPA distance in metres.

3.12 data window period

DWP

t_{DW}

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

Note 1 to entry: In formula form:

$$t_{DW} = \frac{l_{DW}}{v}$$

where l_{DW} is the data window length in metres and v is the ship speed in metres per second.

3.13

nominal hydrophone angle

angle between the horizontal axis and the line created between the point at the sea surface above the ship reference point at CPA and the location of the hydrophone

Note 1 to entry: For the purpose of ISO 17208, for measurements at a CPA-distance smaller than the local water depth, the nominal hydrophone angles are 15°, 30° and 45° below the horizontal plane.

3.14

hydrophone cable drift angle

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

3.15

seabed critical angle

ψ_c

grazing angle in water below which sound waves are totally reflected at the seabed

Note 1 to entry: If the seabed is modelled as a fluid with speed of sound c_b , the critical angle is given by $\psi_c = \cos^{-1}(c_w / c_b)$, where c_w is the speed of sound in water.

3.16

measurement system

data acquisition system consisting of, but not limited to, one or more hydrophone(s), conditioning preamplifier(s), analogue-to-digital converter(s), computer and ancillary peripherals, or autonomous recorder combining the above functionality in one instrument

3.17

system sensitivity

quotient of the root-mean-square open-circuit output signal at a specified point in the measurement system (usually the electrical output terminals) to the incident root-mean-square sound pressure that would be present at the position of the reference centre of the hydrophone in the undisturbed free field if the hydrophone was removed for specified frequency and specified direction of plane wave sound

Note 1 to entry: The system sensitivity is defined here for an acoustic measurement system designed to measure sound pressure signals in water. The measurement system will typically consist of hydrophone(s) connected to amplifier(s) and filter(s) and will feed an output voltage into a digital acquisition and storage system. Note that the response of the hydrophone(s), amplifier(s) and filter(s) will in general vary with frequency.

Note 2 to entry: For an *analogue* system, the output signals are electrical voltages, and the sensitivity is described in terms of the electrical voltage developed per pascal of acoustic pressure, and is stated in units of V/Pa. The system sensitivity level can be expressed in decibels with reference to 1 V/μPa.

Note 3 to entry: For *digital* systems, the output is a digital waveform (rather than an analogue voltage output). Here, the calibration of the digitiser (analogue to digital converter) is incorporated into the overall sensitivity of the whole system. This is termed the *digital system sensitivity*, which is the number of digital counts per unit change in sound pressure (unit Pa⁻¹).

Note 4 to entry: In general, the measuring system may introduce a phase delay into the measured signal. This may be accounted for by representing the system sensitivity as a complex valued quantity, the modulus of which represents the magnitude-only response, and the phase of which describes the phase delay. For calculation of acoustic metrics which depend on the energy or power in the signal (e.g. SPL), the system phase response is of little significance.

Note 5 to entry: The system sensitivity is defined here as an acoustic free-field sensitivity using the free-field sensitivity of the hydrophone. If the hydrophone is physically attached on to another body such as an acoustic recorder or float (rather than deployed on an extension cable), diffraction and scattering of sound by the body may affect the free-field sensitivity at kilohertz frequencies, causing enhanced directivity compared to the response of the free hydrophone.

3.18

calibration

method of using known inputs, possibly using physical stimuli (such as a known, calibrated and traceable acoustic source) or electrical input (charge or voltage signal injection) at the input (or other stage) of a measurement system

3.19

mean-square system-filtered sound pressure

$$\overline{p'^2}$$

integral over a specified time interval of squared weighted sound pressure, divided by the duration of the time interval, for a specified frequency range, when the linear filter is a specified underwater acoustic measuring system (3.16)

Note 1 to entry: Mean-square system-filtered sound pressure is expressed in pascals (Pa).

Note 2 to entry: See ISO (18405:2017), entry 3.7.1.1 *weighted sound pressure*.

3.20

mean-square system-filtered sound pressure level

$$L_{p'}$$

ten times the logarithm to the base 10 of the ratio of the *mean-square system-filtered sound pressure* (3.19) to the specified reference value, p_0^2 , in decibels

Note 1 to entry: Mean-square sound pressure level is the level of the power quantity equal to the mean-square sound pressure, denoted p^2 . In formula form, $L_{p'} = 10 \log_{10} (\overline{p'^2} / p_0^2)$ dB.

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

Note 3 to entry: In underwater acoustics, the reference value of mean-square sound pressure, p_0^2 , is 1 μPa^2 . The reference value shall be specified.

Note 4 to entry: The averaging time and frequency range shall be specified.

4 General measurement requirements

4.1 General

To perform a measurement of the sound radiated by a ship in shallow water, there are number of factors which need to be addressed, including selection of an appropriate test site, suitable deployment of hydrophones, appropriate choice of instrumentation, and proper operation of the vessel³⁾ under test. The following steps are to be followed:

4.2 Test ship parameters

- a) The user selects the ship of interest, with a specified overall length and draught.
- b) The user selects the configuration (propulsion power and machinery settings, with tolerance) to achieve the speed through the water for which the radiated sound is to be measured. Power and machinery operation should be held constant throughout repeat runs (5.4).

NOTE Ship radiated sound, particularly propeller cavitation noise, will be impacted to a varying degree by local wind and current effects, so speed over ground is not a suitable parameter.

- c) The user defines the acoustic ship length L over which the ship is assumed to radiate the dominant sound. Dependent on the location of the dominant sound sources on the ship under test, this can be the

3) In the context of this standard the terms 'ship' and 'vessel' are used as synonyms.

overall length of the ship (from bow to stern) or the length of the aft part of the ship, where the propellers and the main engines are located.

- d) The user defines ship reference point: transversely at the ship centre line, longitudinally at the centre of the selected length L , and vertically at the nominal source depth, i.e. at 0,7 times the ship's draught.

4.3 Frequency range

The user selects the frequency range of interest over which SL is required, following ISO 17208-1, which specifies a minimum frequency range that covers the decade bands with nominal centre frequencies from 10 Hz to 20 000 Hz (band indices -20 to 13, inclusive).

NOTE Decade bands span one tenth of a decade and are also known as one-third octave (base 10) bands [ISO 18405].

4.4 CPA distance

Ship radiated sound measurements are to be made with hydrophone(s) located at a horizontal distance from the ship track, to measure the beam (starboard / port) aspect of the ship under test. The user selects a horizontal closest point of approach (CPA) distance between the ship track and the hydrophone location, that fulfils the following requirements:

- The distance at CPA between the nearest hydrophone and the ship reference point shall be greater than the acoustic ship length.

NOTE This ensures that the distance between the hydrophone(s) and all positions on the acoustic ship length (see 4.2 c) do not deviate by more than 10 % from the distance between the hydrophone and the ship reference point, so that the ship can be described as a point source.

- The minimum horizontal CPA distance shall be limited to achieve a minimum data window period of 10 s. The minimum CPA distance depends on ship speed v [m/s] and can be calculated from [Formula \(1\)](#):

$$d_{\text{CPA,min}} = \frac{t_{\text{DW,min}} \times v}{2 \tan(30^\circ)} \approx (8,7 \text{ s}) \times v \quad (1)$$

NOTE A data window period of 10 s results in an uncertainty of 0,7 dB in the calculation of the SPL in the lowest (10 Hz) frequency band (see [F.2](#)).

- The maximum CPA distance shall be limited, to avoid signal-to-noise problems and to reduce uncertainty associated with propagation loss estimation (see [Clause 7](#)). It is advised to limit the CPA distance to a maximum of five times the local water depth.
- The hydrophone deployment shall not affect safe manoeuvring of the ship under tests.

4.5 Test site selection

The user selects a measurement site, that fulfils the following requirements:

- Ideally, the water depth is larger than the CPA-distance (see [4.4](#)).
- The measurements can be performed in water with a depth smaller than the required minimum CPA distance (see [4.4](#)). It is advised to select a water depth greater than one fifth of the required minimum CPA-distance.
- The water depth should be uniform over the area that covers the ship track length over which the ship radiated sound is measured as well as the hydrophone locations, to within 10 %.
- The speed of sound in the seabed in the measurement area should be uniform to within 10 %. A sandy seabed is preferred, to avoid immersion of bottom mounted hydrophones in soft sediment.

- Sediment layers, particularly where soft sediment overlays a hard substrate or where the seabed contains gaseous layers, can have a substantial influence on sound propagation. Sites with such properties are to be avoided where possible.
- The user should be aware that shallow water effects can affect ship resistance and hence have influence on the ship radiated sound. ISO 15016^[2] specifies that ship resistance measurements for a ship of width B [m] and draught D [m] at speed v [m/s] is affected if the water depth H [m] is smaller than the larger of the values obtained from the two formulas:

$$H_{\min} = 3\sqrt{BD} \text{ and } H_{\min} = (0,3 \text{ s}^2 / \text{m}) \cdot v^2$$

- The background noise at the test site should be low enough to permit measurement of the underwater sound of the ship under test over the frequency range of interest. That means that the background noise in the area (including the sound from ships passing at distance from the measurements site) is preferably at least 10 dB below the sound pressure level from the ship under test at the hydrophones, in all decade bands in the frequency range of interest (4.3).

NOTE Performing background noise measurements at the intended test site prior to the ship measurements is recommended. Where applicable, the expected sound pressure level of the ship at the hydrophones can be estimated on the basis of statistical ship source level models, see e.g. Reference [3], in combination with an estimation of propagation loss, see [Clause 7](#).

4.6 Sea surface conditions

Sea surface conditions can negatively impact underwater noise measurements. Higher sea states increase background noise and affect sound propagation which may degrade the trial results. Observation of the sea surface conditions during the measurements should use WMO Code Table 3700 (Douglas Scale).^[4] The maximum acceptable sea state during the trials is Code Figure 3 (Slight), referred to as “sea state 3”. This corresponds with a maximum significant wave height of 1,25 m. The authority conducting the trial may consider reducing this limit for vessels with an overall length of < 100 m, which may require more benign surface conditions.

NOTE WMO Code Table 3700^[4] uses the total state of agitation of the sea resulting from various factors such as wind, swell, currents and angle between swell and wind.

4.7 Acoustic measuring instrumentation

The measuring system generally consists of the following instruments: hydrophone(s); amplifier(s) and signal conditioning equipment; digitization and storage equipment.

The amplifier can be a separate element in the system with an adjustable gain or may be an integral part of the hydrophone with no possibility for gain adjustment. Digitization is provided by an analogue to digital converter (ADC) and the electronic storage is typically provided by a computer hard disk or solid state memory.

4.7.1 System sensitivity

The sensitivity of the measuring system should be chosen to be an appropriate value for the amplitude of the sound being measured. The aim in the choice of the system sensitivity is to avoid a poor signal-to-noise ratio for low amplitude signals as well as to avoid distortion and clipping for high amplitude signals, over the desired frequency range.

NOTE 1 To build in some flexibility, it is preferable to have some selectable gain in the amplification stages, or in the settings of the ADC. These can then be set to appropriate values once the sound levels are known after some initial measurements. However, note that for autonomous recorders and hydrophones which have integral preamplifiers, the gain cannot usually be modified after deployment.

NOTE 2 Ideally the same hydrophone and gain settings are used for the background noise measurements and the measurement of the sound radiated from the vessel under test. A hydrophone with low-noise performance and high sensitivity is generally preferred.

NOTE 3 If extra cable is added to a hydrophone which does not have an integral preamplifier, this will reduce the overall sensitivity for the hydrophone due to the extra electrical loading caused by the capacitance of the extension cable. Either the hydrophone is calibrated with the extension cable connected, or the effect of the electrical loading is calculated (see IEC 60565-1[5]). For hydrophones that have an integral preamplifier within the hydrophone body, adding extension cable will not affect the sensitivity.

NOTE 4 Hydrophones with integral amplifiers have either differential or single ended outputs. It is important to ensure that hydrophone, cable and receiver are configured consistently, and calibration is performed for the same configuration.

4.7.2 Frequency range and sampling rate

The measuring system shall record sound pressures over the desired frequency range (as specified in 4.3). This implies that all components in the signal chain, including hydrophone, amplifier, and filter, shall pass signals within the desired frequency range.

NOTE 1 The requirement for unambiguous representation of the signals within the desired frequency range requires the sampling rate, f_s , of the ADC within the recording system to be greater than 2,4 times the upper bound frequency of the highest decade band of the desired frequency range. This also requires the use of an anti-alias filter at the input to the ADC, to suppress signal frequencies above the Nyquist rate.

NOTE 2 It is desirable that the system sensitivity be invariant with frequency over the frequency range of interest (i.e. that it possess a “flat response”), to within a tolerance of 2 dB. It is possible to correct for the variation in the sensitivity with frequency with better accuracy than the above tolerance if the hydrophone and measuring system is calibrated over the full frequency range of interest.

NOTE 3 For analysis in broad frequency bands (for example decade bands), the instrumentation must be capable of covering the lower and upper limits of the lower and upper frequency bands respectively.

4.7.3 Directivity

The hydrophone (or hydrophone and recorder) used shall have an omnidirectional response such that its sensitivity is invariant with the direction of the incoming sound wave to within a tolerance of 2 dB over the frequency range of interest.

NOTE 1 This requirement is not difficult to satisfy at frequencies up to 20 kHz in the XY (horizontal) plane, and for the majority of the XZ and YZ (vertical) planes of the hydrophone response [see IEC 60500], which defines the angular range of significance for the hydrophone. For angles of incidence close to the body or cable of the hydrophone (or body of the recorder), the directivity is likely to show greater variation due to shielding of the hydrophone element. When deploying the hydrophone or recorder, care should be taken to orient the device to minimize this shielding effect. One issue that can cause enhanced directionality is where the hydrophone is deployed close to another structure that is capable of reflecting the sound waves. This effect can be evident at kilohertz frequencies if the hydrophone is deployed close to a support structure such as a heavy mooring or support, or a recorder case that houses electronics and batteries but is mostly air-filled. Similarly, if the hydrophone has a guard deployed around it, this can influence the directivity at kilohertz frequencies. If necessary, the above effects can be quantified by directional response measurements of the hydrophone together with the mounting, in a free-field environment.

4.7.4 System self-noise

The system self-noise (the noise generated by the system in the absence of any signal due to an external acoustic stimulus), expressed as equivalent sound pressure level in decade bands, shall be at least 10 dB below the sound pressure level from the ship under test at the hydrophones, in all decade bands in the frequency range of interest (4.3), see also 4.5.

4.7.5 Dynamic range

The highest expected sound pressure at the measurement position, shall be measurable without distortion or saturation caused by the hydrophone, amplifier, and ADC.

NOTE 1 High amplitude sounds that are beyond the maximum capability of the measuring system will cause distortions in the measured data. For example, clipping can occur where the peaks of the signal are missing from the data (the peaks being truncated at the full-scale value of the system ADC). The measuring system is required to be linear up to the highest expected sound pressure.

NOTE 2 A method to mitigate problems with dynamic range is to have some flexibility in the sensitivity, often achieved by use of adjustable gains for amplifier stages and scale settings on ADCs. However, where a system has been deployed remotely (for example, an autonomous recording system), control over the system settings after deployment might not be possible. In this case, some knowledge of the likely range of sound pressure levels is required to optimize the available dynamic range (this knowledge can be obtained from for example prior recordings at the same location, from reported levels in the scientific literature or from approximate theoretical calculations).

NOTE 3 If special ships are to be ranged in various conditions (e.g. cavitating and non cavitating propeller) the level difference between those conditions can be significant. Thus, it is important, that the dynamic range of the measurement system is sufficiently high to cover these conditions without distortion and loss of data quality.

4.7.6 Full system calibration

The full measuring system shall be calibrated over the full frequency range of interest, as specified in [4.3](#).

The calibration of the hydrophones shall be traceable to national or international primary standards of measurement, with calibrations conducted in conformance with IEC 60565-1[5] and/or IEC 60565-2[6].

NOTE 1 It is possible to calibrate a hydrophone and recording system with a combined expanded uncertainty of better than 1 dB (expressed at a 95 % confidence level). It is preferred that the time duration between full laboratory calibrations is not more than two years, and that a field calibration check (see [4.7.7](#)) be carried out before and after every major deployment or sea-trial.

NOTE 2 Calibration data for hydrophones and measuring instrumentation are typically expressed at a succession of discrete frequencies, or in the form of a calibration curve. If the recorded data are already processed into decade bands before the correction for hydrophone sensitivity is applied, the required calibration values are the mean sensitivities for each of the frequency bands. Where the hydrophone sensitivity is not flat, a constant value across the band cannot be assumed.

4.7.7 Field calibration checks

In-situ field checks on the system calibration should be undertaken immediately pre-deployment and post instrument recovery and in between any repeated deployments.

NOTE 1 To do this, it is advisable to make use of a commercially available hydrophone-calibrator, which provides the hydrophone with a signal of known amplitude at a single-frequency (commonly 250 Hz). The calibrator typically consists of an air-pistonphone that generates a known sound pressure level inside a small coupler into which the hydrophone is inserted. The sound pressure depends on the free-volume inside the coupler when the hydrophone is inserted, and so the coupler is calibrated for each type of hydrophone that is used with it. Although the hydrophone calibrator provides a check at only one frequency, it does allow the entire system to be checked using an acoustic stimulus.

NOTE 2 It is also possible to undertake an electrical check calibration of the system components. If the hydrophone in use has an insert voltage capability (many commercial hydrophones with integral preamplifiers have this facility), this can be used to check the electrical integrity and perform a calibration by electrical signal injection. This is a useful technique when deploying long cabled systems from vessels and can be performed without retrieving the hydrophones. However, the method does not perform an acoustical check on the hydrophone element.

4.7.8 Data quality

If data compression formats are used in order to increase the storage capacity (and thereby the recording duration), the data compression techniques used shall be lossless, or the effect on the data quality shall be demonstrated. All analysis shall be carried out on uncompressed data.

Any crucial auxiliary data or metadata that are needed for interpretation of the results should be recorded (for example, the settings of the ADC, or the gains of any amplifiers, the sampling rate and the resolution).

If data storage is required to be long-term (many years), consideration should be given to the likely future compatibility of the storage media and data format. Note that some formats and storage media become obsolete over time.

NOTE It is desirable that such calibration data information be included in a file header or log file so that the information is kept with the data. Though a number of suitable data formats exist (for example, WAV file format), there is no standardised format for storing ocean sound data.

4.8 Distance measurement

This document requires determining the slant range distance between the hydrophones and the position at the water surface above the ship reference point of the ship under test when it is at CPA (see [Clause 7](#)). The expanded uncertainty of the estimated slant range shall not exceed 10 %.

The slant range r from the position at the water surface above the ship reference point to the hydrophone(s) may be computed by applying Pythagoras' rule to the horizontal CPA distance (d_{CPA}) and the hydrophone depth (d_h), as given by [Formula \(3\)](#):

$$r = \sqrt{d_{\text{CPA}}^2 + d_h^2} \quad (3)$$

The horizontal location of the ship reference point while the ship sails over the required track (see [5.3](#)) can be calculated from a recording of the ship location and heading. Many ships carry a receiver for a GNSS (global navigation satellite systems) or a terrestrial radio navigation system that can provide such a recording. Alternatively, the location of the ship can be measured laser-optically from an auxiliary measurement platform. The measured distance shall be corrected for the distance between the location of the GNSS system or the laser reflection location and the ship reference point.

How to determine the location of the hydrophones depends on the type of deployment (see [4.9](#)).

- For surface-suspended vertical hydrophone arrays, the location of the surface buoy can be measured directly (e.g. laser-optical, GNSS, radar). The nominal depth of the hydrophones below the surface buoy can be measured from the length of the suspension system. It may be necessary to take into account drift that the hydrophones could experience after they are deployed. The hydrophone cable drift angle can be reduced, by attaching a weight to the end of the hydrophone cable. Surface deployed arrays should include at least one depth gauge between the deepest hydrophone and the end weight, to enable calculating the actual hydrophone depths.
- For bottom-mounted and bottom-tethered hydrophone arrays, the horizontal location can be estimated from the measured deployment location at the surface, using the GNSS of the deployment vessel. The uncertainty of this estimation increases with water depth. The uncertainty can be reduced via a direct check by divers or underwater vehicles, or from acoustic triangulation, using an acoustic transponder system (e.g. from an acoustic release). Bottom-mounted arrays should preferably include a depth gauge. Bottom-tethered arrays should include at least one depth gauge below the buoy that supports the array and upper hydrophone, to enable calculating the actual hydrophone depths. The hydrophone cable drift angle can be reduced by applying more buoyancy and by minimizing drag.

4.9 Hydrophone deployment

4.9.1 General

One of the following generic deployment methods shall be adopted, depending on available resource and conditions. A number of typical deployment configurations are possible, many of which are presented in the scientific literature. Recommended configurations are shown in [Annex A](#).

4.9.2 Vessel based deployments

This involves deployment of hydrophones and/or recorders (either individually, or in arrays) from a support vessel, with the analysis and recording equipment remaining on the vessel, which can be either anchored or drifting. The method has the advantage that deployments can be quick and mobile, and a relatively large area can be covered fairly cost-effectively. The risk of losing instrumentation is low, the data can be monitored as they are acquired, and instrument settings can be adjusted in real time to provide the optimum settings for high quality data (for example to avoid saturation and distortion). This deployment method is suitable for measuring ship radiated sound, especially if there is a need to measure the acoustic field as a function of range from the source. The support vessel should not interfere with the measurements (see [4.9.5](#)) and during the measurements the support vessel shall be positioned outside the observation angle ($\pm 30^\circ$ at CPA, see [Figure A.1](#)).

4.9.3 Static deployments (bottom-tethered systems)

For measurements in shallow waters, it is recommended to use static bottom-tethered configurations.

A bottom-tethered deployment is preferable to a surface deployment to minimize parasitic signals from the influence of surface wave action, to keep the hydrophone away from the pressure-release water-air surface, and to minimise disturbance by surface vessels. Bottom mounted and bottom-tethered are also more robustness against flow noise.^[7] Cost effective solutions for most deployments are autonomous recorders, which are archival and store data on internal memory with the data only available after recovery. Recovery requires either an acoustic release system or a surface buoy deployed from a seabed anchor, which enables the recorder to be hauled to the surface.

4.9.4 General criteria for deployments

The deployment method shall meet the following criteria:

- The method shall enable the hydrophones to be positioned at a known depth in the water column (or height above the seabed).
- The method shall enable the hydrophones to be positioned at a known distance from the CPA of the vessel under test.

The deployment method shall provide mitigation from contaminating parasitic signals where required (see [4.9.5](#)).

4.9.5 Minimization of self-noise

In addition to the self-noise of the measuring system itself, the measured data can also be contaminated by noise originating from the platform or method of deployment. This is sometimes called “platform noise” or “deployment noise” and excludes the electronic self-noise of the instrumentation. These parasitic signals are due to the deployment method for the hydrophone and recording system and its interaction with the surrounding environment (e.g. current, wave action, etc.). Care shall be taken in the design of the deployment systems to avoid contamination from these sources. Often, the presence of the contaminating signals is not easy to predict or to detect (even though it is present in the data). The platform-related deployment noise will in general add to the system self-noise and to the background noise.

Mitigation of platform-related self-noise is discussed in [Annex B](#).

5 Measurement configuration

5.1 Number of hydrophones

The use of a three-hydrophone array (vertical or horizontal) is recommended, however a single hydrophone may be used. The advantages of using an array can be summarised as follows:

- a hydrophone array facilitates averaging over different values of propagation loss, leading to a more robust estimation of source level (see [Clause 7](#)) than for a single hydrophone. This robustness manifests itself in a lower uncertainty estimate for a three-hydrophone array than for a single hydrophone ([Table 1, 8.2.1](#)). A vertical array results in a slightly lower uncertainty for frequency bands above 100 Hz than a horizontal array.
- Second, an array offers redundancy because if one hydrophone or measurement channel fails, there is a back-up. Additionally, it simplifies the process of identifying a transducer that may be out of tolerance.

5.2 Hydrophone deployment configuration

The hydrophone deployment configuration depends on the water depth and the minimum CPA distance (as specified in [4.4](#)). It shall be selected according to the following criteria:

- In water depths greater than the CPA distance apply the hydrophone configuration specified in ISO 17208-1. This consists of an array of three hydrophones at depths corresponding with 15°, 30° and 45° vertical observation angles at CPA (nominal hydrophone angle). As a minimum, apply a single hydrophone at a depth corresponding with a nominal hydrophone angle between 15° and 45°.
- In water depths smaller than the CPA distance, various configurations are possible:
 - a) A vertical array of at least three hydrophones, evenly distributed over the lower two-thirds of the water depth.
 - b) A horizontal array of at least three bottom-mounted or bottom tethered hydrophones, evenly distributed between the minimum range for CPA distance (see [4.4](#)) and a maximum distance of five times the water depth.
 - c) A single hydrophone in the lower half of the water column.

The hydrophones can be cabled to a multi-channel recorder (on a measurement platform at the sea floor or at the sea surface) or consist of autonomous systems which individually record the hydrophone output. The clocks of the recorders shall be synchronized to within 1 s.

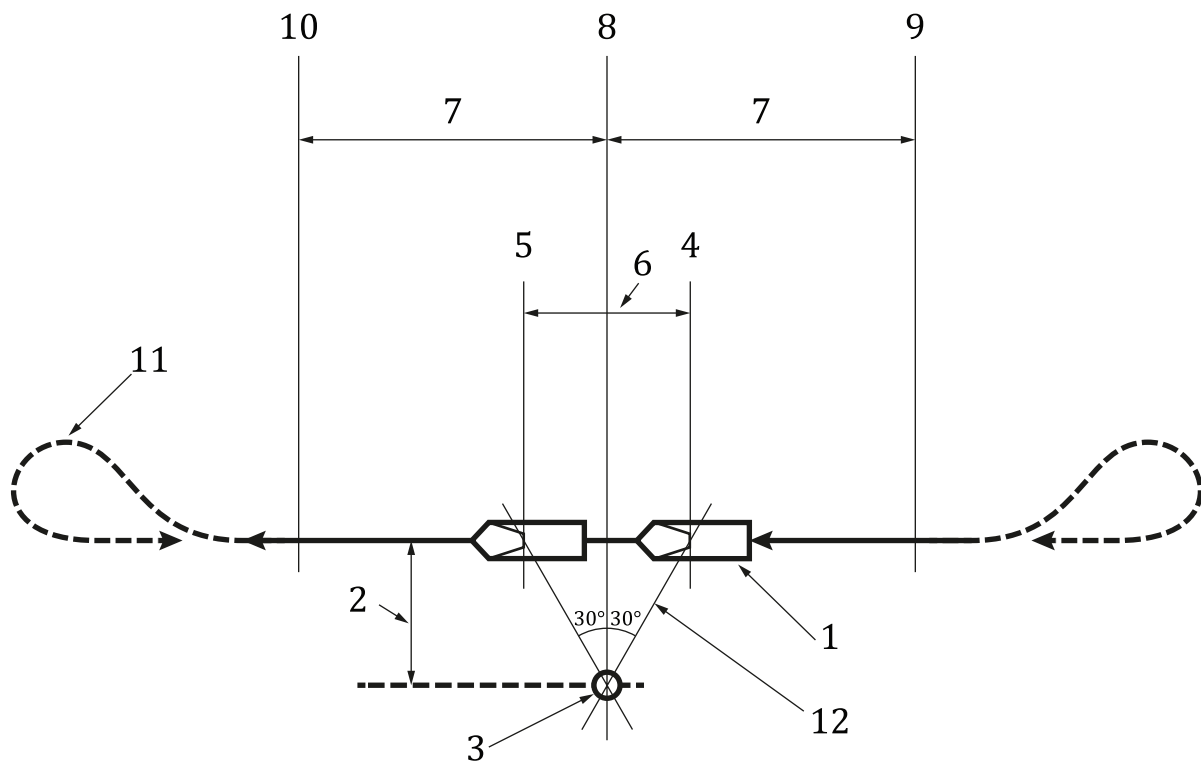
5.3 Test course and ship operation

The run configuration is shown in [Figure 1](#). 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 propeller shaft rotation rate, fixed machinery conditions and minimum use of helm to maintain course between COMEX and FINEX.

A single run results in a measurement of the ship radiated noise in one beam aspect of the ship (port or starboard). A full measurement of the radiated noise requires measurements in both aspects. These can be achieved by either deploying a measurement system on each side of the ship track, or by carrying out multiple runs, as illustrated in [Figure 2](#).

The run configuration for a single array is presented in [Figure 1](#) and achieves the required geometry by using an appropriate turn on completion of the first pass to achieve a reciprocal track. The critical factors that shall be considered in achieving this are as follows:

- The manoeuvre shall result in the vessel achieving a reciprocal track that passes the required distance from the transducer array on the opposite beam and on a heading that deviates no more than $\pm 10^\circ$ from the track of the first pass.
- The effects of the turn on the propulsion system/propellers/propulsors shall have returned to a steady state at COMEX (9).
- The effects of the turn on helm demands should have ceased at COMEX (9).
- The vessel should minimise helm movements during the transit between start and end data Points (4/5).
- Machinery settings on each run shall be the same (e.g. lever settings / propeller shaft rotation rate / propeller pitch) and should not be corrected for environmental factors to achieve a consistent speed over the ground (SOG).
- It is recommended not to vary the CPA distance by more than $\pm 20\%$ for the set of runs for the condition at which the radiated noise of the vessel is to be measured.



a) Run 1 (Port)