COMPARISON OF ULTRASONIC HYDROPHONE CALIBRATIONS
IN THE FREQUENCY RANGE 0.5 MHz to 20 MHz

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TECHNICAL PROTOCOL DOCUMENT COVERING THE BIPM/CIPM Key Comparison
CCAUV.U-K4 (hydrophone free-field open-circuit sensitivity in the megahertz frequency range).
COMPARISON OF ULTRASONIC HYDROPHONE CALIBRATIONS
IN THE FREQUENCY RANGE 0.5 MHz TO 20 MHz

1 INTRODUCTION

1.1 Purpose of the document

This document describes the procedure to be used during the BIPM/CIPM Key Comparison CCAUV.U-K4. This comparison covers the calibration of ultrasonic hydrophones used within the megahertz frequency range i.e. 0.5 MHz to 20 MHz, and in particular the determination of their free-field open-circuit sensitivity.

This is a repetition of the Key Comparison CCAUV.U-K2 “Comparison of 1 mm hydrophone calibrations in the frequency range 1 to 15 MHz” (1999 – 2003), but whose scope has been extended upwards to 20 MHz and downwards to 0.5 MHz. A report of the previous Key Comparison is available on the BIPM web-site under report number NPL Report DQL-AC (RES) 013 (2005). The reduction in the lower frequency for CCAUV.U-K4 ensures that it will overlap with the Underwater Acoustics Key Comparison CCAUV.W-K1 which covers the range 1 kHz to 0.5 MHz.

1.2 Organisation of key comparison

The co-ordinating institute (Pilot Laboratory) is the United Kingdom National Physical Laboratory (NPL). As well as organising the key comparison, NPL will perform reference calibrations of the hydrophones prior to and after the completion of the comparison. NPL will also be responsible for collating the reports received from the Participating Laboratories and generating the final Key Comparison Report. Additionally, it will undertake spot-checks on the devices during their return from participating institutes to ensure their stability. Four other institutes (Participating Laboratories) whose contact details may be found in Annex A have agreed to take part in the comparison and these are:

PTB (Germany)

NMIJ/AIST (Japan)

NIM (China)

INMETRO (Brazil).

1.3 Schedule of calibrations

The Key Comparison has been organised as a “star” comparison, with the two hydrophones being returned to the Pilot Laboratory to enable stability checks to be completed. The time-table is shown below.
1.4 Hydrophone details

The type of hydrophone to be used within the comparison is a polyvinylidene fluoride (PVDF) membrane hydrophone of the bilaminar design manufactured by Marconi Technology Centre. Two hydrophones will be circulated to each of the Participants Laboratories for calibration. Their active element diameters of 1 mm have been chosen to provide sufficient sensitivity for them to be calibrated using absolute methods. Figure 1 represents a photograph of such a hydrophone. If required, NPL can provide participants with a similar membrane hydrophone prior to their calibrations, in order that appropriate mounts may be designed and experience in their use gained. Other hydrophones will be kept at NPL and recalibrated periodically to check the stability of the reference measurement facility at NPL. Additional devices will be held in reserve in case the main hydrophones are damaged.

1.5 Hydrophone pre-amplifier details

In calibrating a hydrophone it is often necessary to use a preamplifier which has a low input capacitance (less than 10 pF) as this reduces the effect of electrical loading on the hydrophone. A suitable amplifier [1] will be circulated with the hydrophones which the participants may use if they wish. The amplifier operates from voltages of 0 and ±15 V which is to be supplied by the user. The input impedance of the amplifier has been measured at NPL and is approximately equivalent to 6 pF in parallel with 50 kΩ. Correction factors are given in Table 1 which will permit the measured sensitivities to be corrected to open-circuit values. The gain of the amplifier should be measured by the participant at each calibration frequency and should be reported along with the other calibration results.
1.6 Parameter to be reported – the Measurand

The sensitivity of the hydrophone which must be reported is the end-of-cable open-circuit sensitivity [2]. This is defined as the ratio of the instantaneous open-circuit voltage at the end of any integral cable or output connector of a hydrophone to the instantaneous acoustic pressure in the undisturbed free field of a plane wave in the position of the reference centre of the hydrophone if the hydrophone were removed [2].

The sensitivity should be measured for each of the two hydrophones at frequencies of 0.5, 1, 2.25, 3.5, 5, 10, 15 and 20 MHz. The measurement temperature should be specified by all participants, with NPL correcting the results to 20 °C. Purely for information purposes, the temperature variations in sensitivity of this type of hydrophone at various frequencies varies within the range -0.05 and +0.2 % °C⁻¹.

1.7 Transportation

Participating Laboratories are responsible for transporting the hydrophones back to the Pilot Laboratory. It is preferable that the hydrophones are hand-carried and transported in the passenger cabin. If this is not possible the hydrophones must be transported back to NPL by air freight using temperature controlled pressurised cargo hold.

The two hydrophones and preamplifier will be packaged in a transit case and accompanied by an ATA carnnet. Participating institutes shall comply with customs regulations. When the package is transported back to NPL unaccompanied, the carnnet must be included with other forwarding documents so that the handling agent can obtain customs clearance. In no case should the carnnet be packed within the package.

![Figure 1: Photograph of a Marconi bilaminar membrane hydrophone of the type which will be used within the key comparison. The outside diameter of the supporting ring is 130 mm.](image-url)
2 PRACTICAL NOTES

2.1 Receipt of hydrophones

The Participating Laboratory shall inform the Pilot Laboratory of the arrival of the hydrophones unless the pilot institute was involved in transporting the hydrophones in-person. After receipt the participating institute shall immediately check the hydrophones for any damage and ensure they are working correctly.

2.2 Care of the hydrophones

The hydrophones should not be subject to temperatures outside the range 0 – 40 °C or exposed to continuous bright sunlight. They should not be driven electrically as this could cause damage: however, if it is necessary to measure the electrical impedance, the voltage used should be less than 0.5 V (rms). The impedances have been measured at NPL (see Table 2) so it should not be necessary for the participants to do this.

2.3 Condition of water for calibrations

The conductivity of the water used in the calibrations should be noted during the measurements and should ideally be below 5 µS (resistivity greater than 0.5 MΩ cm). The water should have been degassed prior to use, as this eliminates the possibility of air bubbles forming on the hydrophone and reduces the probability of cavitation occurring. After about 7 hours in a test tank, degassed water becomes saturated with air again, but at NPL it has not been found necessary to repeat the degassing process each day. As an extra precaution against bubble formation, it is advisable to soak the hydrophone in freshly degassed water for at least 30 minutes before use.

For membrane hydrophones, it is possible for large air bubbles to become entrapped under the supporting ring. Such bubbles should be removed carefully using a small soft brush. The membrane hydrophones are supplied with an earthing pin which should be connected to a metallic object in the tank, such as the hydrophone mount. The conductivity and oxygen content of the water should be measured during the calibrations and recorded on the reporting sheet (Table 3).

The temperature of the water should be measured (preferably to an accuracy of ± 0.1 °C) throughout the calibration.

2.4 Guidelines on the use of hydrophones

2.4.1 Alignment

The definition of hydrophone sensitivity given in Section 1.5 is incomplete, because it does not define the orientation of the hydrophone with respect to the incoming wave. To find this direction, the hydrophone should be placed with its active element (the side where the membrane is almost flush with the ring) pointing towards the transducer and roughly perpendicular to the incoming wave, and then it should be rotated in two directions about its active element until the maximum received signal is obtained. To obtain this maximum it should only be necessary to rotate the hydrophone by a few degrees.
2.4.2 Spatial-averaging

If it is necessary to make corrections for spatial-averaging at the hydrophone element it should be noted that the effective radius of a membrane hydrophone can be significantly different from its geometrical radius, particularly at frequencies below 2 MHz and below, where the effective radius can be much larger than expected. The frequency dependent radii of the two membrane hydrophones are given in Table 3.

3 EXPERIMENTAL PROCEDURE

3.1 Perform calibrations, taking particular note of the water temperature and calibration frequency. If any problems arise that may delay the measurements please contact NPL immediately to arrange a revised completion date.

3.2 At each frequency perform at least 4 independent calibrations of each hydrophone, preferably on different days and with the hydrophone removed from the tank between measurements. Report each set of results on one of the sheets provided (see Table 4).

3.3 Calculate the mean of the measurements and the Type A (random) standard uncertainty.

3.4 Report the final result on the summary sheet (Table 5), along with the estimated Type B (systematic) standard uncertainty and the expanded (overall) uncertainty at each frequency. The expanded uncertainty should be obtained by combining Type A and Type B uncertainties according to the procedure given in reference [3].

3.5 Provide a full written description of the calibration method, detailing the information required in Annex B and in particular noting any special problems encountered during the measurements.

3.6 Having previously made appropriate arrangements with NPL, return the hydrophones and results to NPL, preferably by a member of the participating institute’s staff. Failing this, they should be transported back to NPL by air freight using temperature controlled pressurised cargo hold.

4 REPORTING

4.1 After the Participating Laboratories have completed their measurements, they must draft a report describing their measurements using the Guidelines contained within Annex B of this technical Protocol. This should be submitted to the Pilot Laboratory no later than one month after the completion of the measurements of the Participating Laboratory.

4.2 The Pilot Laboratory will complete the Key Comparison Draft A Report following the Guidance provided in the document “Guidance for carrying out key comparisons with the CCAUV”, generated by the CCAUV Key Comparison Working Group (www.bipm.org/utils/en/pdf/CCAUV-GoC). This will be submitted to the Participant Laboratories for comment by the Pilot Laboratory no later than three months after the final checks on the hydrophones have been completed at the Pilot Laboratory.
5 UNCERTAINTIES

CIPM guidelines require participating institutes submit their complete uncertainty budget in advance of participation. An uncertainty budget must therefore be submitted by each Participating Laboratory to the Pilot Laboratory prior to the commencement of their measurements. Changes in this declared uncertainty budget, subsequent to the Laboratory completing measurements, are acceptable, providing the reasons for the change in expanded uncertainty and/or any specific uncertainty components is explained in detail.

The uncertainty budget must include the principal components of uncertainty contributions at each frequency, and all necessary information justifying how these were derived [3]. In addition to these principal components of the uncertainty, common to all of the participants, individual institutes may add any others they consider appropriate, again sufficient explanatory background information.

6 REFERENCES


Table 1: Open-circuit correction factors for the hydrophones utilised within this comparison, when used with the NPL preamplifier serial number 5564166LF. The measured sensitivity should be multiplied by the numbers given below.

<table>
<thead>
<tr>
<th>Hydrophone serial number</th>
<th>Frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>ER070</td>
<td>1.0519</td>
</tr>
<tr>
<td>IP999</td>
<td>1.0722</td>
</tr>
</tbody>
</table>

Table 2: Impedance of hydrophones in Ω.

<table>
<thead>
<tr>
<th>Hydrophone serial number</th>
<th>Frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>ER070</td>
<td>Real</td>
</tr>
<tr>
<td></td>
<td>Imaginary</td>
</tr>
<tr>
<td>IP999</td>
<td>Real</td>
</tr>
<tr>
<td></td>
<td>Imaginary</td>
</tr>
</tbody>
</table>

Table 3: Effective radius of hydrophones in mm (from IEC standard 62127-3-am1. Ed1.0; Ultrasomics - Hydrophones - Part 3: Properties of hydrophones for ultrasonic fields up to 40 MHz, Geneva, IEC).

<table>
<thead>
<tr>
<th>Hydrophone serial number</th>
<th>Frequency (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>ER070</td>
<td>0.98</td>
</tr>
<tr>
<td>IP999</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Table 4: Calibration report Sheet.

<table>
<thead>
<tr>
<th>Participating Laboratory:</th>
<th>Calibration method:</th>
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<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date(s) of calibrations:</th>
<th>Hydrophone serial number:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nominal frequency (MHz):

<table>
<thead>
<tr>
<th>Measurement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual frequency (MHz)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature, T (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Open-circuit correction</td>
<td></td>
<td></td>
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<tr>
<td>Water conductivity (µS)</td>
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<td></td>
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<tr>
<td>Oxygen content (mg l⁻¹), or alternative (ppm or % saturation)</td>
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<tr>
<td>Amplifier gain (dB)</td>
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<td></td>
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<tr>
<td>Measured sensitivity (nV/Pa)</td>
<td></td>
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<td></td>
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<tr>
<td>Open-circuit sensitivity at T °C (nV/Pa)</td>
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<tr>
<td>Notes (e.g. of any unusual difficulties)</td>
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</tbody>
</table>
Table 5: Summary sheet.

<table>
<thead>
<tr>
<th>Participating Laboratory:</th>
<th>Method:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Dates:</th>
<th>Hydrophone Serial Number:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Nominal frequency (MHz)</th>
<th>0.5</th>
<th>1</th>
<th>2.25</th>
<th>3.5</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual frequency (MHz)</td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Mean open-circuit sensitivity at T °C (nV/Pa)</td>
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<tr>
<td>Type A (random) standard uncertainty (%)</td>
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<tr>
<td>Type B (systematic) standard uncertainty (%)</td>
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<td></td>
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<tr>
<td>Coverage factor (k)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Expanded uncertainty (%)</td>
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<td></td>
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</tbody>
</table>
Annex A: Addresses and contact details

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Phone +55-21-2679 9720
e-mail: rpfelix@inmetro.gov.br
Annex B: Contents of the final calibration report.

The following provides a checklist of the information required for the final report supplied to NPL which describes the hydrophone calibrations carried out by the participants.

1. How was the water prepared for the calibration?

2. Was the hydrophone soaked in degassed water before use, and for how long?

3. Was the NPL preamplifier used? If not, describe how the open-circuit correction was obtained.

4. Was it necessary to determine the gain of the preamplifier? If so, describe the method, and estimate its accuracy.

5. What type of tank was used (give the size and material used in construction) and how were any earth or shielding connections made?

6. How were any corrections for spatial-averaging obtained?

7. What acoustic pressure was used at each frequency of calibration?

8. What propagation distance(s) was (were) used at each calibration frequency?

Describe the calibration method used, including any special features and any difficulties that were encountered during the measurements.