COOMET.AUV.W-S1 supplementary comparison of free-field hydrophone calibrations in the frequency range 250 Hz to 8 kHz

A E Isaev[1], Chen Yi[2], A N Matveev[1] and Ping Zihong[2]

1 Russian National Research Institute for Physicotechnical and Radio Engineering Measurements, Mendeleevo, Moscow region 141570, Russia

2 Hangzhou Applied Acoustics Research Institute, Fuyang, Hangzhou, Zhejiang province, 311400, P.R.China

Corresponding author: A E Isaev, isaev@vniiftri.ru

Abstract: A description is given of COOMET.AUV.W-S1 supplementary comparison of free-field hydrophone calibrations in the frequency range 250 Hz to 8 kHz between Hangzhou Applied Acoustics Research Institute – a pilot and Russian National Research Institute for Physicotechnical and Radio Engineering Measurements. Two standard hydrophones of TC 4033 and GI 55 were calibrated in this comparison. Reciprocity method, comparison methods, and their facilities were used to assess the current state of free-field hydrophone calibration in the frequency range 250 Hz to 8 kHz of China and Russia. The consistency of calibration results between two participants was confirmed, and the maximum deviation observed was 0.59 dB at frequency 400 Hz.

Key words: Metrology; supplementary comparison; free field; hydrophone calibration

1. Introduction

In order to provide technical data to underpin the expansion of hydrophone calibrations in free field to the lower frequencies and expand the calibration and measurement capabilities in underwater acoustics of national metrology institutes who participate in this comparison under an agreement on mutual recognition of MRA CIPM [1], a supplementary comparison of free-field hydrophone calibrations in the frequency range 250 Hz to 8 kHz was held between Hangzhou Applied Acoustics Research Institute (HAARI, DI for Underwater Acoustics, China) and Russian National Research Institute for Physicotechnical and Radio Engineering Measurements (VNIIFTRI, DI CIPM MRA, Russia) [2].

This supplementary comparison was approved by COOMET in November, 2011 with its comparison identifier of 531/RU/11 based on the successful completion of bilateral COOMET Russian-Chinese pilot comparison of hydrophone calibrations in the frequency range 250 Hz to 200 kHz (comparison identifier: 473/RU-a/09) [3], and was registered in the KCDB of BIPM in April, 2012, the new comparison identifier was COOMET.AUV.W-S1.

According to the technical protocol of COOMET.AUV.W-S1 agreed by HAARI and VNIIFTRI [4], the pilot laboratory HAARI was designed as the coordinator, and the free-field hydrophone calibrations were carried on during the 8th October to 17th October, 2012 in Hangzhou, China and 18th August to 27th August, 2013 in Moscow, Russia. Measurement and calibration capabilities identifier on CMC classificatory: 12.1.1 was free-field sensitivity (modulus: frequency) of non ultrasound hydrophones.

Two hydrophones of TC 4033 and GI 55 respectively provided by HAARI and VNIIFTRI were used as standard hydrophones in comparison. This paper describes the standard hydrophones, calibration methods and their facilities, calibration results and conclusions.

2. Standard hydrophones used in comparison

The standard hydrophones used in comparison were a TC 4033 hydrophone manufactured by Reson A/S in Denmark, its sensitive element was a piezoelectric ceramic sphere with diameter of 20 mm, and a GI 55 hydrophone manufactured by VNIIFTRI, its sensitive element was a piezoelectric ceramic cylinder with diameter of 6 mm and height of 5 mm. The details of two standard hydrophones were listed in Table 1. The calibration frequency ranges were from 250 Hz to 8 kHz with the frequency interval of 1/3 octave. Each participant calibrated the both hydrophones at 16 discrete frequency points.

Table 1. Details of standard hydrophones used in the comparison

Hydrophone type	Manufacturer	Frequency range (kHz)	Nominal sensitivity (250Hz) (dB, *re*:1V/μPa)	Length of integral cable (m)	Nominal capacitance (nF)	Power supply (V)
GI 55	VNIIFTRI	0.25–8	-175	5	integrated amplifier	±12 DC
TC 4033	Reson A/S	0.25–8	-203	10	7.8	No

TC 4033 hydrophone was chosen for it was routinely used as a standard hydrophone in HAARI. Long-term stability and temperature dependence of the TC 4033 hydrophone were investigated to be remarkably stable [3]. GI 55 was a hydrophone with its sensitivity almost 30 dB higher than the TC 4033. Use of this hydrophone can help to reduce the impact of SNR on the calibration results at low frequencies. Long-term stability and resistance to water temperature variation from 14 ºC to 28 ºC in the frequency range 250 Hz to 8 kHz were investigated in VNIIFTRI, and GI 55 proved to be remarkably stable also.

3. Calibration methods and their facilities

3.1. Calibration methods

3.1.1 Calibration methods used by HAARI

Free-field hydrophone calibration by comparison with a standard hydrophone was used as the calibration method for GI 55 and TC 4033 hydrophones in the frequency range 250 Hz to 800 Hz in HAARI. This method requires a calibrated hydrophone and an auxiliary projector [5]. The calibrated hydrophone was replaced by the unknown hydrophone. The ratio of the open circuit voltages of the two hydrophones was equal to the ratio of their free field sensitivities.

Free-field reciprocity method was used as the calibration method for GI 55 and TC 4033 hydrophones in the frequency range 1 kHz to 8 kHz. At least three transducers shall be used for the calibration technique, of which at least one shall be reciprocal [5]. Two of the transducers shall be placed in water in free-field conditions, using one of them as a projector and the other as a hydrophone. With three pairs, three independent electrical transfer impedances shall be obtained. From these quantities, the free-field sensitivity of the hydrophone can be obtained [3].

3.1.2 Calibration methods used by VNIIFTRI

In VNIIFTRI, free-field hydrophone calibration by comparison with a standard hydrophone was used as the calibration method for GI 55 hydrophone in the frequency range 250 Hz to 8 kHz, and free-field reciprocity calibration method was used as the calibration method for TC 4033 hydrophone in the frequency range 250 Hz to 8 kHz.

3.1.3 CMWA method used by HAARI and VNIIFTRI

In order to eliminate the reflections from the boundaries of the anechoic and reverberant water tank at low frequencies, the Complex Moving Weighted Averaging (CMWA) method [6] was applied in free-field comparison calibration of HAARI and VNIITRI, and in free-field reciprocity calibration of VNIIFTRI. Figure 1 shows the schematic diagram of the processing procedure of CMWA method with radiation of continuous chirp signals.

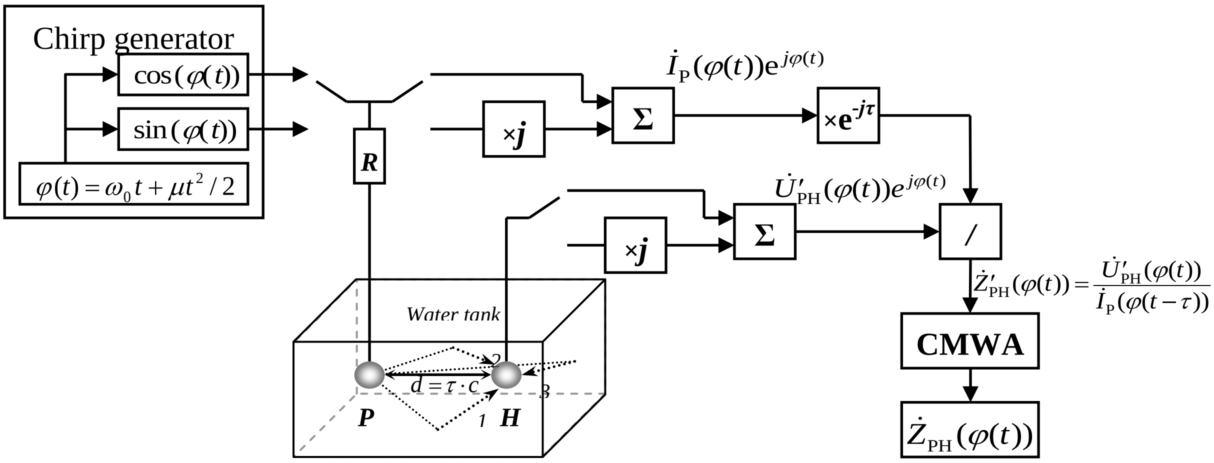

Figure 1. Schematic diagram of the processing procedure of CMWA method

A chirp signals with its instantaneous phase of $\varphi(t)$=$\omega_0(t)$+$\mu t^2/2$ (μ is a sweep rate) and its quadrature chirp signals were transmitted alternately by the projector. And a CMWA processing technique [6-8] was applied to the frequency response of transfer impedance of projector and hydrophone pair.

3.2. Calibration facilities

3.2.1 Free-field comparison calibration facility used in HAARI

Figure 2 shows the schematic diagram of calibration facility using free-field comparison method used in HAARI. When measuring, the calibrated hydrophone and unknown hydrophones were placed in the far field of the auxiliary projector at the depth of 5 m in an anechoic water tank of 50 m long, 15 m wide and 10 m deep with their reference centers into an equilateral triangle arrangement. The distance between projector and hydrophones were 2 m. Quadrature supplemented chirp signals were transmitted, the coherent accumulation technique and CMWA technique were used to improve the SNR of open-circuit voltages of hydrophones and signal processing.

The auxiliary projector was a Modular Projector System (MPS), which was assembled from a number of small sound projectors that were mounted in close proximity to each other. The MPS can work in the frequency range 200 Hz to 1 kHz, and has its resonance frequency around 290 Hz. A RHSA 20 hydrophone with an integral pre-amplifier manufactured by HAARI was used as the reference hydrophone, its sensitive element was a piezoelectric ceramic sphere with diameter of 20 mm, and its sensitivity was -157 dB at 250 Hz. The expanded uncertainty (with coverage factor k=2) of hydrophone calibration in the frequency range 250 Hz to 800 Hz was estimated at 0.9 dB [9]. The water temperature was 23.3 °C when measuring GI 55 hydrophone, and was 22 °C when measuring TC 4033 hydrophone.

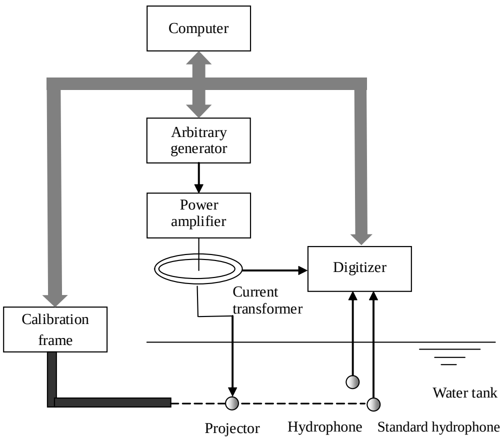

Figure 2. Schematic diagram of free-field comparison calibration facility used in HAARI

3.2.2 Free-field reciprocity calibration facility used in HAARI

Figure 3 shows the schematic diagram of calibration facility using free-field reciprocity method used in HAARI. When measuring, a pair of projector and hydrophone were mounted to a calibration framework through their free-flooding carbon fiber poles with the shape of the framework likes a “π” at the depth of 5 m in an anechoic water tank of 50 m long, 15 m wide and 10 m deep. The distance between the projector and hydrophones was 0.3 m. A tone-burst signal was transmitted, the coherent accumulation technique and DFT was used to improve the SNR of open-circuit voltages of hydrophones and signal processing.

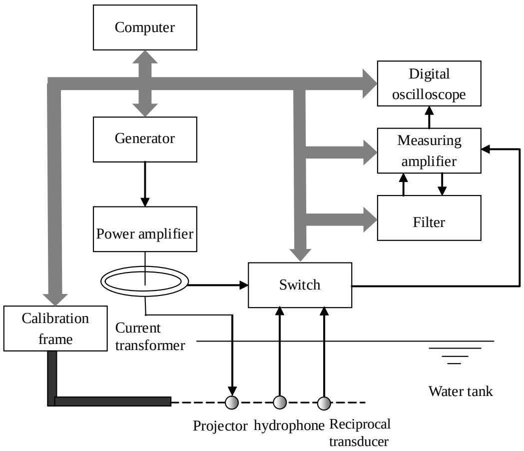

Figure 3. Schematic diagram of free-field reciprocity calibration facility used in HAARI

The auxiliary projector and reciprocal transducer were RHS 30 hydrophones which manufactured by HAARI. Its expanded uncertainty (with coverage factor k=2) of hydrophone calibration in the frequency range 1 kHz to 8 kHz was estimated at 0.7 dB [9]. The water temperature was 22.8 °C when measuring GI 55 hydrophone, and was 21.4 °C when measuring TC 4033 hydrophone.

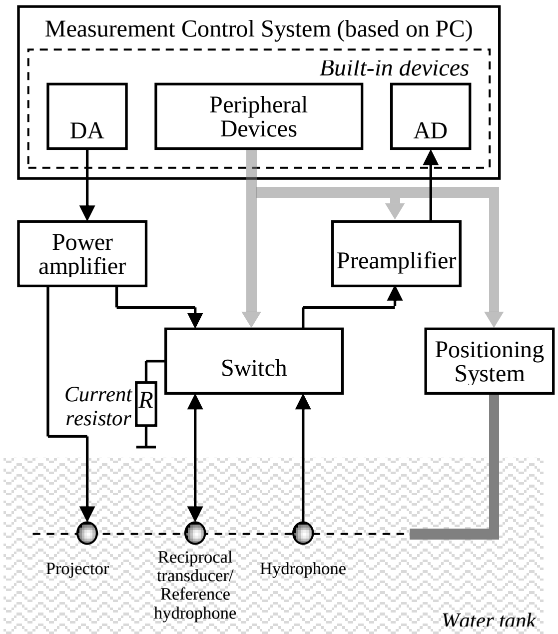

Figure 4. Schematic diagram of free-field calibration facility used in VNIIFTRI

3.2.3 Free-field calibration facility used in VNIIFTRI

Figure 4 shoes the schematic diagram of calibration facility using free-field comparison method and reciprocity method used in VNIIFTRI. When measuring, the transducers were placed at depth of 3 m in a reverberant water tank of 10 m long, 6.5 m wide and 5.8 m deep using thin fishing lines vertical suspension. The distance between projector and receiver was 0.9 m - 1.0 m when using the comparison method, and was 0.6 m - 0.8 m when using the reciprocity method. A laser beam and the acoustic method were used for measuring distances to reduce the errors in positioning of transducers on the angle and the depth. Quadrature supplemented chirp signals were transmitted, the coherent accumulation technique and CMWA technique were used to improve the SNR of open-circuit voltages of hydrophones and signal processing.

The auxiliary projector and reversible transducer were model ITC 1001 spherical ominidirectional transducers manufactured by International Transducer Corporation in USA, the active element of ITC 1001 was a piezoelectric ceramic sphere with diameter of 110 mm. The reference hydrophone was a B&K 8104 hydrophone with well researched sensitivity. The expanded uncertainty (with coverage factor *k*=2) of hydrophone calibration in the frequency range 250 Hz to 8 kHz was estimated at 0.6 dB for comparison method and 0.5 dB for reciprocity method [9]. The water temperature was (20 ± 1) °C when measuring GI 55 hydrophone, and was (17 ± 1) °C when measuring TC 4033 hydrophone.

4. Calibration results

4.1 Introduction

Two standard hydrophones were calibrated by different time, places and persons using different calibration methods and facilities and the water temperature of comparison calibration was also different. The calibration results from both participants' data were not corrected for temperature.

4.2. Calibration results of GI 55 hydrophone

The free-field sensitivity calibration results of GI 55 hydrophone were shown in Tables 2. It can be clearly seen that the calibration results from HAARI and VNIIFTRI were very close: the maximum deviation was 0.20 dB at frequency 250 Hz, which was much less than the expanded uncertainties declared by HAARI and VNIIFTRI respectively.

Table 2. Comparison calibration results of GI 55 hydrophone

Freq. (Hz)	M_{CH} (dB, *re* 1V/μPa)	U_{CH} (dB)	M_{RUS} (dB, *re* 1V/μPa)	U_{RUS} (dB)	M_{ref} (dB)	U_{ref} (dB)	Δ_{CH} (dB)	$U_{\Delta CH}$ (dB)	Δ_{RUS} (dB)	$U_{\Delta RUS}$ (dB)
250	-174.60	0.9	-174.89	0.6	-174.80	0.50	0.20	0.76	-0.09	0.33
315	-174.73	0.9	-174.85	0.6	-174.81	0.50	0.08	0.76	-0.04	0.33
400	-174.72	0.9	-174.89	0.6	-174.84	0.50	0.12	0.76	-0.05	0.33
500	-174.68	0.9	-174.70	0.6	-174.69	0.50	0.01	0.76	-0.01	0.33
630	-174.66	0.9	-174.70	0.6	-174.69	0.50	0.03	0.76	-0.01	0.33
800	-174.65	0.9	-174.66	0.6	-174.66	0.50	0.01	0.76	0	0.33
1000	-174.77	0.7	-174.66	0.6	-174.71	0.46	-0.06	0.54	0.05	0.39
1250	-174.82	0.7	-174.70	0.6	-174.75	0.46	-0.07	0.54	0.05	0.39
1600	-174.92	0.7	-174.75	0.6	-174.82	0.46	-0.10	0.54	0.07	0.39
2000	-174.75	0.7	-174.80	0.6	-174.78	0.46	0.03	0.54	-0.02	0.39
2500	-174.93	0.7	-174.80	0.6	-174.85	0.46	-0.08	0.54	0.05	0.39
3150	-174.88	0.7	-174.66	0.6	-174.75	0.46	-0.13	0.54	0.09	0.39
4000	-174.85	0.7	-174.75	0.6	-174.79	0.46	-0.06	0.54	0.04	0.39
5000	-174.85	0.7	-174.89	0.6	-174.87	0.46	0.02	0.54	-0.02	0.39
6300	-174.90	0.7	-174.80	0.6	-174.84	0.46	-0.06	0.54	0.04	0.39
8000	-175.13	0.7	-175.29	0.6	-175.22	0.46	0.09	0.54	-0.07	0.39

M_{CH} and M_{RUS} are sensitivity levels measured by HAARI and VNIIFTRI respectively, U_{CH} and U_{RUS} are expanded uncertainties declared by HAARI and VNIIFTRI respectively, M_{ref} and U_{ref} are comparison reference value which was calculated as the weighted average of M_{CH} and M_{RUS} and its expanded uncertainty, Δ_{CH} and Δ_{RUS} are deviation from reference value for HAARI and VNIIFTRI respectively, $U_{\Delta CH}$ and $U_{\Delta RUS}$ are degrees of equivalence for HAARI and VNIIFTRI respectively.

4.3. Calibration results of TC 4033 hydrophone

The free-field sensitivity calibration results of TC 4033 hydrophone are shown in Table 3. It also can be seen that the calibration results from HAARI and VNIIFTRI are very close: the maximum deviation was 0.59 dB at frequency 400 Hz, which was much less than the expanded uncertainties declared by HAARI.

Table 3. Comparison calibration results of TC 4033 hydrophone

Freq. (Hz)	M_{CH} (dB, *re* 1V/μPa)	U_{CH} (dB)	M_{RUS} (dB, *re* 1V/μPa)	U_{RUS} (dB)	M_{ref} (dB)	U_{ref} (dB)	Δ_{CH} (dB)	$U_{\Delta CH}$ (dB)	Δ_{RUS} (dB)	$U_{\Delta RUS}$ (dB)
250	-201.95	0.9	-201.5	0.5	-201.59	0.44	-0.36	0.80	0.10	0.24
315	-201.85	0.9	-201.6	0.5	-201.66	0.44	-0.19	0.80	0.06	0.24
400	-202.38	0.9	-201.6	0.5	-201.79	0.44	-0.59	0.80	0.17	0.24
500	-201.78	0.9	-201.7	0.5	-201.74	0.44	-0.04	0.80	0.01	0.24
630	-202.38	0.9	-201.7	0.5	-201.87	0.44	-0.51	0.80	0.14	0.24
800	-202.10	0.9	-201.7	0.5	-201.79	0.44	-0.31	0.80	0.09	0.24
1000	-201.97	0.7	-201.7	0.5	-201.78	0.41	-0.19	0.58	0.10	0.29
1250	-201.90	0.7	-201.7	0.5	-201.75	0.41	-0.15	0.58	0.07	0.29
1600	-202.25	0.7	-201.7	0.5	-201.89	0.41	-0.36	0.58	0.18	0.29
2000	-202.20	0.7	-201.7	0.5	-201.88	0.41	-0.32	0.58	0.15	0.29
2500	-202.23	0.7	-201.8	0.5	-201.91	0.41	-0.32	0.58	0.15	0.29
3150	-202.37	0.7	-201.8	0.5	-201.99	0.41	-0.38	0.58	0.19	0.29
4000	-202.30	0.7	-201.9	0.5	-202.00	0.41	-0.30	0.58	0.14	0.29
5000	-202.35	0.7	-201.9	0.5	-202.07	0.41	-0.28	0.58	0.14	0.29
6300	-202.40	0.7	-202.0	0.5	-202.10	0.41	-0.30	0.58	0.15	0.29
8000	-202.48	0.7	-202.1	0.5	-202.22	0.41	-0.26	0.58	0.13	0.29

5. Conclusions

From the calibration results of Tables 2 and 3, the following conclusion can be drawn:

1) For GI 55 hydrophone, the consistency of calibration results between HAARI and VNIIFTRI was confirmed. The maximum deviation of 0.20 dB was observed at frequency 250 Hz, which is much less than the expanded uncertainties (at k=2) of 0.90 dB of HAARI using free-field comparison method with CMWA technique, and 0.60 dB of VNIIFTRI using free-field comparison method with CMWA technique.

2) For TC 4033 hydrophone, the consistency between HAARI and VNIIFTRI was also confirmed. The maximum deviation observed was 0.59 dB at 400 Hz, which is less than the expanded uncertainty (at k=2) of 0.90 dB of HAARI using free-field comparison method with CMWA technique, and much less than the combined expanded uncertainty (at k=2) of 1.03 dB between HAARI and VNIIFTRI.

As a conclusion, the comparison calibration between HAARI and VNIIFTRI was successful. Although different calibration methods, techniques and sound fields are used, good consistencies of calibration results of two standard hydrophones are still achieved. It proved that the limitation of calibration frequency in free field can be extended to 250 Hz in a reverberant water tank of 10 m long, 6.5 m wide and 5.8 m deep by using CMWA technique.

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Appendix A: Uncertainty estimation of calibration method used in comparison

A1. Free-field comparison method with CMWA technique used in HAARI

Uncertainty estimation of hydrophone calibration using free-field comparison method with CMWA technique is listed in Table A.1.

Table A.1 Uncertainty estimation of free-field comparison method

	Source of uncertainty	Value(dB)
type B	Deficiency of input impedance of digitizer assumed	0.10
	Deviation of directivity of auxiliary projector assumed	0.12
	Interfere of reflections from the boundaries of water tank assumed	0.06
	Nonlinearity of auxiliary projector measured	0.12
	Incorrect measurement of open-circuit voltage assumed	0.07
	Incorrect measurement of transmitting current assumed	0.07
	Incorrect measurement of distance assumed	0.06
	Measurement uncertainty of the reference hydrophone	0.30
	Interfere of irregular noise assumed	0.08
	Interfere of electromagnetism assumed	0.06
type A	Standard uncertainty of measurement of sensitivity	0.08
	Expanded uncertainty (coverage factor *k*=2)	**0.9**

A2. Free-field reciprocity method with tone-burst radiation used in HAARI

Uncertainty estimation of hydrophone calibration using free-field reciprocity method with tone-burst radiation is listed in Table A.2.

Table A.2 Uncertainty estimation of free-field reciprocity calibration method

	Source of uncertainty	Value (dB)
type B	Deficiency of input impedance of preamplifier assumed	0.06
	Incorrect transform of current transformer assumed	0.05
	Quantization error of digital oscilloscope assumed	0.06
	Reciprocal deviation of reciprocal transducer measured	0.15
	Nonlinearity of transducer measured	0.12
	Deviation of directivity of transducer assumed	0.10
	Deviation of vertical position of transducer assumed	0.10
	Incorrect measurement of distance assumed	0.05
	Incorrect density of water assumed	0.02
	Incorrect frequency of generator assumed	0
	Incorrect steady state of tone-burst assumed	0.23
	Interfere of irregular noise assumed	0.06
	Interfere of electromagnetism assumed	0.05
type A	Standard uncertainty of measurement of sensitivity	0.08
	Expanded uncertainty (coverage factor *k*=2)	**0.7**

A3. Free-field calibration method used in VNIIFTRI

Uncertainty estimation of hydrophone free-field calibration is listed in Table A.3.

Table A.3 Uncertainty estimation of free-field calibration method

	Source of uncertainty	Value (dB)
type B	Influence of transducers directivity	0.01
	Violation of far-field conditions	0.16
	Accuracy of transducer voltage ratios measuring	0.14
	Accuracy of reciprocal transducer current measuring	0.04
	Accuracy of the transducers separation distance measuring	0.04
	Interference due to water tank boundary reflections	0.04
	Accuracy of the reference hydrophone	0.40
	Errors due to averaging of projector-receiver free-field transfer impedance frequency response	0.07
	Not excluded remains of crosstalk	0.08
	Accuracy of electrical load correction	0.05
type A	Standard uncertainty of measurement of sensitivity	0.08-0.09
Expanded uncertainty (coverage factor *k*=2)		**0.6 (comparison method) and 0.5 (reciprocity method)**

Appendix B: Reducing of calibration results discrepancies at low frequency in VNIIFTRI

One of the issues which raised in the memorandum of comparison 473/RU/09 was to determine the cause of the divergence on the calibration results at a frequency of 250 Hz. Possible reasons for divergence of results could be the difference of the temperature in the water tank and in the chamber or imperfect of measurement data processing caused by CMWA method.

To clarify this, an additional calibration in a chamber of small volume was performed during comparison 531/RU/11 in VNIIFTRI. To eliminate the influence of temperature, calibration in the chamber was performed at the same temperature of water as in the water tank. With regard to the data processing, the effect of the unevenness of sought-for frequency dependence on the accuracy of the results obtained by the CMWA method was studied. It was found that unevenness of the sought-for frequency dependence at low frequencies and at areas of transducer resonances is the main source of uncertainty inherent to the CMWA method.

To reduce the influence of this source, experimental frequency dependence was edited before CMWA processing using a priori information (at low frequencies) and a posteriori information (at the resonances of the transducers).

Let us explain the mechanism of uncertainty occurrence. The transfer impedance $Z'_{PH}(f)$ of a projector-receiver pair in the sound field of water tank with reflecting boundaries can be written as the product of a pair of transfer impedance in a free field $Z_{PH}(f)$ and the so-called water tank transfer function $H_{PH}(f)$ [10, 11]:

$$Z'_{PH}(f) = Z_{PH}(f) \times H_{PH}(f)\ .$$

Function $H_{PH}(f)$ expressed in a simplified form through the complex functions that characterize phase delays of the reflected waves relative to the direct wave:

$$H_{PH}(f) = 1 + \sum_i \exp\left(-\ j 2\pi\ f\ \tau_i\right).$$

Where, τ_i is the time delay of i-th reflected wave, reflection coefficients is taken equal to unity, the factors characterizing the attenuation of spherical wave with distance are omitted.

Even more simplify the measuring of projector-receiver pair frequency dependence by assuming that the measurements are performed in semi-muffled water tank with a single reflection, as shown in Figure B.1.

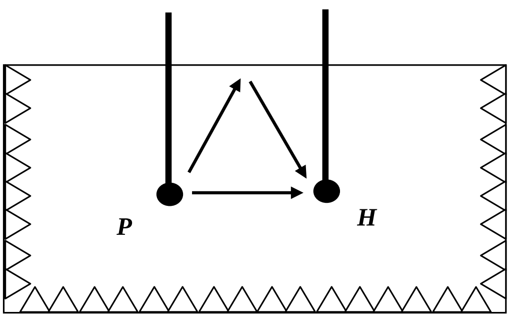

Figure B.1

The transfer function of the water tank with a single reflection, delayed relative to the direct signal at the τ_{ref}, will take the form of a sine wave with a period $1/\tau_{ref}$, as shown in Figure B.2.a.

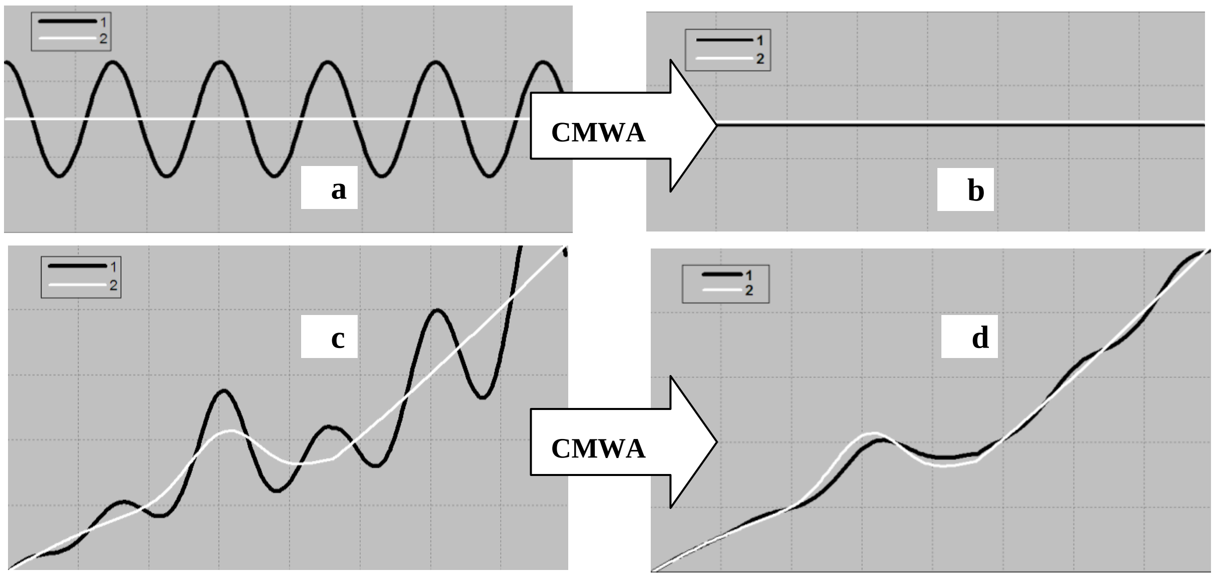

Figure B.2. Curve 1 shows the frequency dependences of the projector - water tank - receiver before (a, c) and after (b, d) CMWA processing, curve 2 shows the frequency dependence of the sought-for free-field projector receiver frequency dependencies

If the frequency response of the projector-receiver pair is flat (do not depend on frequency), the measured frequency dependence of the projector - water tank - receiver will have the same shape as that shown in Figure B.2.a. The idea of the CMWA method consists in a moving weighted averaging of the frequency dependence measured in the water tank. In this case (one reflection) the weighted averaging converted to a simple moving equally weighted averaging in the frequency range $1/\tau_{ref}$. Obviously, the result of such averaging of dependence that shown on Figure B.2 the oscillations caused by a single reflection will be completely excluded. In this case, the averaging does not distort the sought-for frequency response of the projector-receiver pair (see Figure B.2.b).

Let's complicate the situation by assuming that frequency response of projector has a significant unevenness, which is typical for low frequencies. In this case, the oscillation amplitude caused by reflection is dependent on the frequency in accordance with the unevenness of the projector frequency response (see Figure B.2.c).

The result of the CMWA method averaging will not be so perfect. On the one hand, suppression of oscillations will not complete, on the other hand, the sought-for frequency response will be distorted (smoothed) by moving averaging (see Figure B.2.d). Reason for the incomplete suppression of oscillations is that the oscillations are not in the form of a sine function but as a sine function with variable amplitude. The more uneven the sought-for frequency dependence, the greater the distortion caused by the CMWA processing.

If there is a sufficiently exact priori information about the projector frequency response, it can be used to make the measured frequency dependence closer to that shown in Figure B.2 before using the CMWA. This can be done by editing the measured frequency dependence, for example, by dividing it by the a priori frequency response of the projector. In practice, a perfect match with Figure B.2.a can’t be achieved, because getting the absolutely accurate priori information is impossible. However, editing using a priori information allows multiple reduce distortion caused by the smoothing and by oscillations [12].

Thus, editing allows excluding in the measured frequency dependence the unevenness caused by sought-for frequency dependence. We remind that to the result obtained after applying the CMWA method, it is necessary apply the inverse editing.

Figure B.3 shows the steps of obtaining the frequency dependence by CMWA method at radiation of chirp signal with and without editing the experimental frequency dependence.

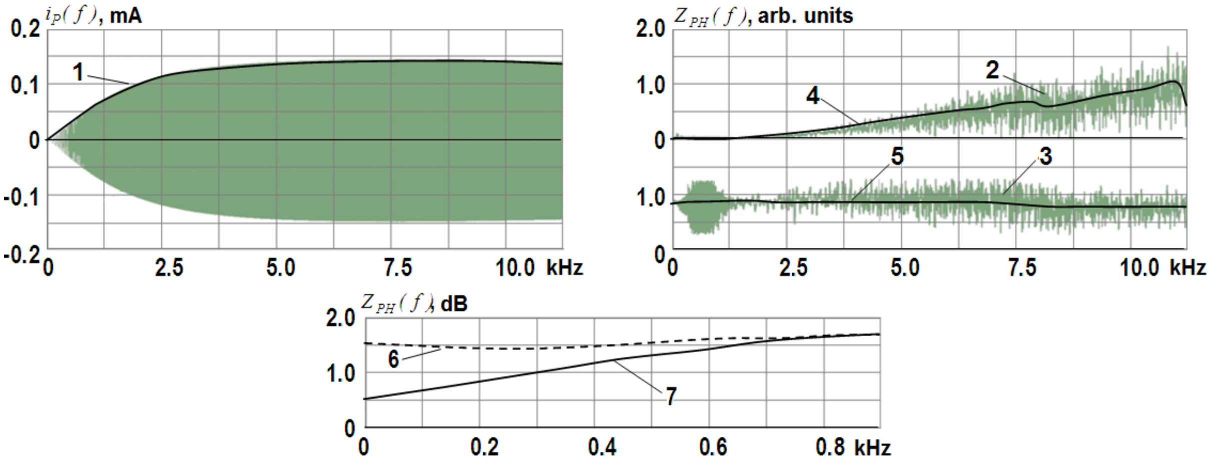

Figure B.3. Frequency dependence: of projector current (curve 1), of projector - water tank - receiver before (curve 2) and after (curve 3) editing, of projector - receiver in free field, obtained by CMWA method with (curve 5) and without (curve 4) editing, low frequency areas of dependencies 4 and 5 - the curves 6 and 7 respectively

In constructing the edit function the frequency dependence of the current through the projector, reciprocity parameter and projector sensitivity on reception were used.

Noticeably the discrepancy at low frequencies of results obtained using (curve 3) and without editing (curve 4). With decreasing frequency, discrepancy between the curves increases and the gain in accuracy from editing (curve 7) reaches a value greater than 1.0 dB.

VNIIFTRI results of hydrophone TC 4033 calibration shown in Figure B.4. Results of free-field calibration and calibration in the chamber of small volume at a frequency of 250 Hz were match, and it was decided to repeat the measurements in the chamber at several frequencies.

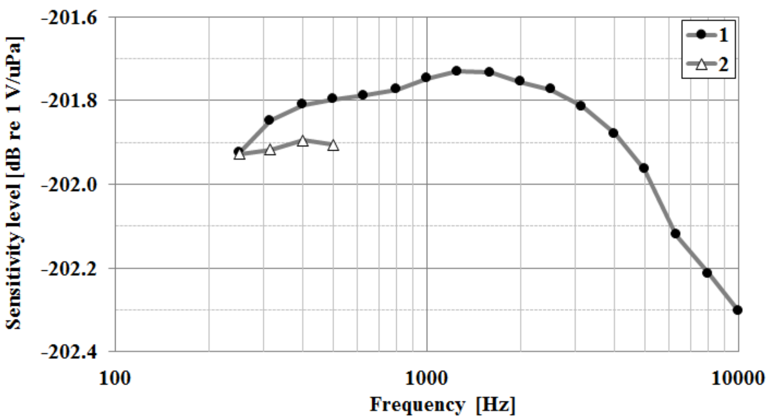

Figure B.4. VNIIFTRI results of hydrophone TC 4033 calibration: free-field (curve 1), in the chamber of small volume (curve 2)

This dependence is shown in Figure B.4 by curve 2. Curve 1 shows the results of free-field calibration of hydrophone TC 4033 by CMWA method at radiation of chirp signal. The discrepancy between the calibrations were nearly three times less than on 473/RU/09 comparisons.

This significant reduction in discrepancies can be explained not so much by eliminating the influence of temperature, how much of using of editing. Along with this, the obligatoriness of priori editing at low frequencies became apparent.

In the absence of a priori information a posteriori editing can be applied, when instead of a priori information the results of first application of CMWA processing is used. At using of a posteriori editing the estimation by CMWA method becomes a multistep procedure at each step of which information about the behavior of the sought-for frequency dependence obtained in the previous step is clarified and accounted [7].