



Publishable Summary for 15RPT02 UNAC-LOW Underwater Acoustic Calibration Standards for Frequencies Below 1 kHz

Overview

The goal of the project is to develop the European Metrological Capacity in underwater acoustic calibration for acoustic frequencies below 1 kHz by providing traceable measurement capabilities to meet the need for calibration of hydrophones and autonomous underwater acoustic noise recording systems. The project will develop the scientific and technical research capabilities in the field within Europe, and provide an improved metrology framework to underpin the absolute measurement of sound in the ocean in support of regulation and EU Directives (such as the Marine Strategy Framework Directive) for which traceability is currently lacking.

Need

There is an increased need for absolute measurements of sound in the ocean driven by ongoing concerns about the environmental impact of human activity, together with the emerging needs of industry and oceanographic science. In order to be meaningful, such absolute measurements require traceability to agreed standards, but traceability is not widely available for acoustic frequencies below 1 kHz. With regard to marine environmental protection, the expansion of offshore activities has led to concern about the environmental impact of man-made sound upon marine fauna. The effect on marine fauna of high amplitude sources may include physiological effects (e.g. damage to hearing) or behavioural effects (e.g. flight response or displacement from habitats). An increase in background noise level may also have chronic effects (e.g. masking of biologically produced sound vital for communication and foraging).

The anthropogenic sources of greatest environmental concern radiate most of their sound energy in the frequency range between 20 Hz and 1 kHz. However, in this frequency range there is a lack of availability of traceable measurement standards, with much of the historic demand being for testing of active systems at kilohertz frequencies. There is a direct and urgent need for traceable calibration of the hydrophone instrumentation used for measurements driven by the increased demand for measurement generated by regulation. However, there is also a technology push provided by the development and increasing commercial availability of new instrumentation, specifically autonomous recorders that combine hydrophones and acquisition and data storage capabilities.

Currently, no standards exist to calibrate these instruments, therefore there is an urgent need to develop traceable measurement capabilities for calibration of hydrophones and autonomous underwater acoustic noise recording systems at frequencies between 20 Hz and 1 kHz, including the 63 Hz and 125 Hz third-octave bands required by the EU MSFD. This must include research to develop new traceable calibration methods for autonomous noise recorders for which there are no established calibration methods. Underwater acoustics is a relatively immature field for metrology, and in addition to establishing a European calibration capability, a strategy must be developed for the long-term operation of the developed capabilities, contributing to a coherent metrology strategy for Europe within this field, providing significant improvement of the use of the available resources to better meet metrological needs and assure the traceability of national standards, and to develop a research capability within the metrology community.

Objectives

The overall objective of this project is to develop an absolute measurement technique for making the calibration of hydrophones and autonomous noise recorders at frequencies between 20 Hz and 1 kHz and the dissemination of the calibration capability in order to fulfil the related directive which is stated in the Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC).

The project addresses the following scientific and technical objectives:

1. To develop traceable measurement capabilities to meet the need for calibration of hydrophones at frequencies between 20 Hz and 1 kHz, and covering the 63 Hz and 125 Hz third-octave bands, as required by the guidelines for monitoring undersea noise within the EU MSFD.
2. To develop calibration methods which provide traceable measurement capabilities to meet the need for calibration of autonomous noise recorders and systems used for long-term ocean acoustic monitoring at frequencies between 20 Hz and 1 kHz, including the 63 Hz and 125 Hz third-octave bands for NMIs and DIs seeking to establish a research capability in this field.
3. To develop an individual strategy for each participant for long-term operation of the developed measurement capabilities including regulatory support, research collaborations, quality schemes and accreditation, contributing to development of a coherent metrology strategy for Europe within this field (discussed and agreed within the EURAMET community via the EURAMET TC-AUV), and significantly increasing the research capacity in the field.

Progress beyond the state of the art

The project will develop and validate appropriate measurement methods for the calibration of hydrophones in the frequency range from 20 Hz to 1 kHz. At the conclusion of the project, at least two of the hydrophone calibration methods selected from those described in the scientific literature or the related international standards will be implemented into new calibration systems. These will be validated by comparison measurements between the project partners. Through this work, traceability for absolute measurement of sound in the ocean using hydrophones will be provided across the EU countries, with project partners offering calibration services from their established facilities to their neighbouring countries.

The calibration methods developed in this project will provide the ability to determine the key acoustic performance characteristics of the recorders, including the self-noise of the hydrophone and system, the hydrophone and system sensitivities. The newly established methods to calibrate autonomous noise recorders will be implemented by the project partners and services offered to stakeholders in neighbouring countries, with recommendations given to technical standards committees including ISO TC43 SC3 (Underwater acoustics) and IEC TC87 (Ultrasonics) for preparation of related standards. This will be facilitated by members of the project consortium who are active in the standards committees (the consortium contains the Convenor of several key Working Groups). The manufacturers and end users of noise-monitoring systems will be informed of the developments so that the improvements can be incorporated into their own work.

Establishing traceable calibration facilities for the hydrophones and noise recorders by the project partners will sufficiently extend the capability of each related stakeholder. Also these calibration facilities shall be used for providing calibration services by NMIs/DIs and guides for end users working in the field on underwater acoustic measurement and monitoring including the design and production of corresponding systems.

Results

The project will facilitate significantly improved capability within Europe for marine acoustic metrology at frequencies below 1 kHz, providing much-needed traceability for absolute measurement of sound in the ocean, and underpinning acoustic measurements for the protection of the marine environment. In addition to the benefits for the metrology community itself, the improvements will also directly benefit the European marine acoustic community, with the main stakeholders being from: industry and end user community. And the relevant regulatory bodies and licensing authorities (both national and international) that require acoustic measurements to be undertaken to satisfy the requirements of EU Directives such as MSFD, offshore licences and environmental impact assessment.

Calibration of hydrophones

As a result of this project, the improved traceability for hydrophone calibration will provide manufacturers and users with vital confidence in the measurement result. "Calibration of Hydrophones for the Frequency Range Between 20 Hz and 1 kHz", the existing methods covered by IEC 60565:2006 has been reviewed to select which methods for low frequency (20 Hz to 1 kHz) hydrophone calibration will be used. Comparison calibration in coupling chamber and standing wave tube methods were selected for further investigation.

A coupling chamber calibration setup has been designed and a technical drawing has been prepared for the

manufacturing process at TÜBİTAK. According to the first design (Chamber 1) one set of coupling chamber has been manufactured and assembled. The coupling chamber was tested and characterized by calibrating a B&K Type 8104 hydrophone in the frequency band from 20 Hz up to 1.5 kHz in air and air-water regimes. Based on first test results, the chamber design was further developed to improve performance at frequencies over 400 Hz. A new designed chamber (Chamber 2) has been developed, manufactured and tested in the frequency band from 20 Hz up to 2 kHz. The calibration procedure was also developed.

For the verification of test results, a B&K 8104 type hydrophone has been circulated between TÜBİTAK, FOI and NPL. FOI calibrated the hydrophone in the frequency band between 20 Hz to 1 kHz by standing wave calibrator unit, NPL calibrated in the frequency band between 5 Hz to 400 Hz by coupling chamber method and TÜBİTAK calibrated in the frequency band from 20 Hz up to 2 kHz by coupling chamber method, in Chamber 2.

A draft uncertainty budget calculation table was prepared and used for evaluation of the uncertainties of the B&K Type 8104 hydrophone calibration.

The extension of primary hydrophone calibration by NPL using free-field reciprocity down to 250 Hz in laboratory tanks (from the previous limit of 1 kHz) has now been described in a paper published in an open-access peer-reviewed journal (reference: Meas. Sci. Technol., 29, 085001, 2018). NPL has developed a full uncertainty budget, and has validated the methodology by comparison with other calibration techniques.

TÜBİTAK, NPL and FOI have agreed that hydrophone B&K 8106 type is selected for intercomparison for second round-robin test. For the calibration of B&K 8106 hydrophone TÜBİTAK has designed and manufactured new coupling Chamber 3 of larger size than the Chamber 2 used for calibration of hydrophone B&K 8104 type. TÜBİTAK has tested the Chamber 3 with B&K 8106 hydrophone in the frequency band from 20 Hz to 2 kHz.

Calibration of autonomous underwater acoustic noise recording systems.

The new methods for calibration of autonomous recorders will provide manufacturers with important feedback on key performance metrics for the first time, leading to the development of improved system performance and validated calibration methods and better uncertainties. The new calibration guidance developed by the project will also be directly used by calibration laboratories, which will assure traceability of measurements performed by end users of recorder systems. This will enable results of in-situ measurements of ocean noise to be reported with a more robust associated uncertainty (1 dB for hydrophones and 1 to 1.5 dB for autonomous sound recorders), which will enable a transparent comparison of measurement results made in different environments and by different users. Moreover, a comparison of the performance of autonomous noise recorders will be possible either individually as a function of time to assess stability, or between differing designs of recorders. This will provide increased reliability and confidence in the performance of instruments for the end-user community. A summary report entitled "Calibration of Autonomous Noise Recorders for the Frequency Range Between 20 Hz and 1 kHz" provides a review of the existing literature and research work, and a description of the methods proposed for the calibration and characterisation of marine autonomous acoustic recorders used for long-term ocean acoustic monitoring. The proposed methods include pressure calibration, free-field calibration and diffuse field calibration. The report describes proposed calibration solutions, and summarises a number of the issues regarding the characterisation of the performance of such devices.

Methods for low frequency pressure calibration of autonomous recorders have been developed at NPL using calibration by comparison to microphones in a closed air-filled chamber. Successful calibrations have been carried out in the frequency range from 5 Hz to 315 Hz. The newly-developed automated software extracts signal levels from the recorder files. Experimental and theoretical investigations have been conducted to determine the effect of non-uniform sound pressure in the chamber. Modelling has been compared to actual measurements at different locations inside the chamber. The effect of uncertainty contributions at (very) low frequencies has been examined.

Initial free-field calibrations have been undertaken by NPL to investigate the effect on the response of resonances in recorder bodies, and these have been compared with finite element modelling. Further free-field measurements (using a dummy recorder) are planned to investigate the effect of resonances in the recorder body.

Trial measurements have also been undertaken by FOI using their standing wave tube facility.

A free-field calibration setup and procedure for deployment, mooring, retrieval of the recorder in open-water

sites and for data extraction and processing has been defined by CNR and ISPRA. An RTsys EA-SDA14 recorder has been rented for testing the calibration setup, with planned overall recording time of about 20 days in two available lakes, to be completed by October 2018.

The round-robin exercise for the calibration of autonomous recorders is underway. A Wildlife Acoustics SM4M recorder was purchased by NPL for use in the validation of calibration procedures by project partners. The recorder was then made available to other project partners for calibration to validate their own capability.

The second project partner to undertake the calibration of the SM4M was FOI who performed a free-field calibration in a deep-water lake facility. The results are similar to those obtained by NPL, showing significant fluctuation in sensitivity at frequencies around a few kilohertz due to interference by scattered sound from the recorder body. NPL and FOI have also observed fluctuations due to body resonances at frequencies below 1 kHz. These results suggest that it would be a good recommendation to use an extension cable to move the hydrophone sensor away from the recorder body. CNR-INM and TÜBİTAK MAM will also calibrate the SM4M recorder as part of the round-robin exercise using their respective setups.

TÜBİTAK has prepared calibration capabilities and developed calibration procedure for the purchased Noise Recorder of RTsys EA-SDA 14 type. Noise recorder is equipped with 10 m cable B&K 8104 to minimize the reflections from noise recorder body. According to request this noise recorder is used to monitor the noise levels of the piling activity during the bridge construction in Dardanelle Strait for 5 days sessions. The frequency band of noise monitoring is from 20 Hz up to 39 kHz. Results are analysed and compared according to the Technical Guidance for Assessing the Effect of Anthropogenic Sound on Marine Mammal Hearing, NOAA Technical Memorandum NMFS-OPR-55 July 2016.

Individual strategy for long-term operation of the developed measurement capabilities

NPL launched a new measurement service for autonomous recorders in 2017. Initially, this provides only pressure calibrations at frequencies from 25 Hz to 315 Hz by use of comparison in a closed chamber. It has already had a total of more than 30 calibrations undertaken for UK regulators, Government institutes, users and manufacturers. The new service was selected by EURAMET MSU as a Good News Story and the relevant article is available at:

https://www.euramet.org/index.php?id=40&tx_news_pi1%5Bnews%5D=622&tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Baction%5D=detail

NPL will extend its CMC capability for free-field calibration down to 250 Hz and increase the scope of its accreditation to ISO 17025. TÜBİTAK will extend its CMC capability for pressure coupling chamber calibration in the frequency band 20 Hz to 1 kHz and increase the scope of its accreditation to ISO 17025.

At CNR, evaluations are under way to integrate calibration capabilities of the existing laboratory, covering the 5 kHz – 300 kHz range, with new capabilities using the open-water site (lake Nemi), where calibration of autonomous recorders might be performed using the available equipment from approximately 100 Hz up to the kHz range (lower end to be confirmed after project results are available and processed). Intercomparison tests with project partners will be organised to verify the validity of calibration results and to fulfil requirements for accreditation in order to achieve status of Designated Institute within Euramet.

Impact

The project and its results have been presented at the following conferences:

- IEEE Oceans in Aberdeen UK in April (NPL)
- European Underwater Acoustic Conference UACE2017 in Greece in September (NPL)
- IMEKO TC19 Workshop on Metrology for the Sea in Naples in October (CNR)
- Participation of TÜBİTAK MAM to International Metrology Congress CIM-2017 in Paris/France on 19-21 September 2017 by fair booth
- Presentation by TÜBİTAK MAM at 8th Naval System Seminar in Ankara/Turkey on 16-17 October 2017.

Furthermore, NPL exhibited the work carried out in this project at the UK Ocean Business exhibition hosted at the UK National Oceanography Centre (NOC) in Southampton in April 2017.

NPL has published a paper in an open-access peer-reviewed journal on the extension of primary hydrophone calibration by NPL using a signal-modelling technique applied to free-field reciprocity down to 250 Hz in laboratory tanks from the previous limit of 1 kHz (reference: *Meas. Sci. Technol.*, 29, 085001, 2018. <https://doi.org/10.1088/1361-6501/aac752>).

The project partners have also published a paper in a peer-reviewed journal describing the work in the UNAC-LOW project (ACTA IMEKO, June 2018, Volume 7, Number 2, 32-38, 2018.
http://dx.doi.org/10.21014/acta_imeko.v7i2.542)

A new design of Coupling Chamber for the calibration of hydrophones at low frequencies is under Patent application by TÜBİTAK. After Patent priority date is taken the corresponding publication will be submitted to peer-reviewed open access journal.

Impact on industrial and other user communities

NPL's new measurement service for autonomous recorders was launched in 2017 and feedback has been highly positive. It has already had a total of more than 30 calibrations undertaken for a variety of target customer groups such as UK regulators, Government institutes, users and manufacturers.

After finalizing round-robin tests, TÜBİTAK will extend its CMC capability for pressure coupling chamber calibration in the frequency band 20 Hz to 1 kHz and increase the scope of its accreditation to ISO 17025. The new service will be provided for the calibration of hydrophones in the corresponding frequency band.

Plans are in an advanced stage for the Stakeholder Workshop to be held at CNR-INM in Rome on September 19th 2018. The UNAC-LOW stakeholder group has 24 contacts (exceeding the expectation from the plan which had a target of 15). The stakeholders include key contacts from manufacturers and suppliers, such as Wildlife Acoustics, RTSys, RSAqua, Ocean Instruments, Ocean Sonics, Teledyne-Reson. Also included are representatives of the user community such as Quiet Oceans, University of Catalunya, Institut für technische und angewandte Physik GmbH, Baker Consultants, CO.L.MAR, and Loughborough University. In addition, there are influential members of the regulatory authorities in both Europe (eg Marine Scotland) and the USA (eg NOAA). The group also includes metrology institutes (eg NIST, VNIIFTRI) and standards bodies (ISO TC43 SC3, IEC TC87 WG15). The stakeholder group reflects a truly worldwide interest in the project outputs, not just a European interest, with countries represented such as UK, France, Spain, Germany, Italy, USA, Canada and New Zealand.

A total of 5 training courses by NPL and 2 training courses by TÜBİTAK have been run since the start of the project, each of which covered the scope of the UNAC-LOW project. The application sectors of the customers are varied the courses were targeted at different communities, such as regulators, manufacturers, metrology organisations, and government institutes and Navies. The beneficiaries include: a marine environmental regulator in the UK, a Government metrology institute from South Africa, an oceanographic institute from Japan, a defence agency from Canada, and Turkish Naval Forces. A training workshop was also held for a mixed UK audience from industry on Ocean Acoustic Measurement. During the courses, low frequency calibration of hydrophones and autonomous recorders was covered (among other topics).

NPL gave a presentation describing the project at the UK Underwater Sound Forum (run by the UK Marine Science Coordination Committee) in November 2017 to a receptive audience of about 50 people (targeted at the UK community including regulators, users, manufacturers and research institutes)

NPL displayed a poster illustrating the objectives and work of the project at the 61st Marine Measurement Forum hosted at NPL in May 2018. The meeting was attended by 67 people from industry, academia and government institutes.

NPL attended the Oceanology International exhibition in London in March 2018 and met with a number of users and suppliers of marine acoustic recorders, during which time the UNAC-LOW project was described.

NPL also attended the Undersea Defence Technology (UDT) exhibition in Glasgow during which meetings were held with a major UK manufacturer of marine acoustic recorders.

The project has been registered on the web-portal ResearchGate, where conference presentations are uploaded, and a variety of stakeholders follow the project using this forum (24 followers, 134 reads of posted publications).

The project webpage (which has public access and a part restricted for partners) is regularly updated with the latest progress.

Impact on relevant standards

In the work of IEC TC87 WG15, NPL has made significant contributions were made) to the extensive revision of IEC 60565, part 2: 'Calibration of hydrophones: Procedures for low frequency pressure calibration'. The standard is directly relevant to the work of this project (WP1). This has now been successfully balloted as a CDV and will be submitted for DIS ballot in late 2018. It should be published shortly after the end of the UNAC-LOW project. NPL has also led revision of IEC 60565, part 1: 'Calibration of hydrophones: Procedures for free-field calibration of hydrophones', which has had a successful CD ballot and will soon reach CDV. NPL has already made significant contributions the recently published ISO standards, ISO 18405:2017 and ISO 18406:2017, and to the draft of ISO 17208-3, where key input was provided on hydrophone and instrument calibration requirements for measurements of low frequency sound sources in the ocean, underpinning the traceability of such measurements.

At the June 2018 plenary meeting of IEC TC87 in the Czech Republic, a New Work Item Proposal for development of standards for calibration of marine acoustic recorders and digital hydrophones was agreed. A resolution was agreed to form a joint working group (JWG) with ISO TC43 SC3. The Convenor of the JWG will be provided by NPL, and the JWG will have input from UNAC-LOW partners.

In the Standards and Calibration sub-committee the prestigious International Quiet Oceans Experiment (IQOE), UNAC-LOW partners have contributed to technical discussions. As part of this committee, a list of currently available standards in the field has been drafted, and a list of world-wide calibration facilities is being drawn up. As part of the activities, NPL attended a meeting in Washington DC on standardisation for ambient ocean noise monitoring where NPL presented current activities on low frequency calibration (including the work of UNAC-LOW).

Impact on the metrology and scientific communities

Partners will continue to working on their individual strategies for the long-term development of the operational capabilities. Discussions on a coherent European metrology strategy for the field were initiated within EURAMET TC-AUV and will be on the agenda for the next TC-AUV meeting in May 2019.

Further efforts have been expended on building in the requirement for the metrology outputs provided by UNAC-LOW into other research projects and initiatives to their direct benefit. UNAC-LOW is represented by NPL and FOI in an INTERREG EU project that started in January 2018 called JOMOPANS. The project aims to provide a framework for ambient noise monitoring for the North Sea in response to the EU MSFD. The outputs of UNAC-LOW are providing underpinning metrology for JOMOPANS, with NPL responsible for preparing project standards and procedures (including for calibration and deployment). This is an example of the direct uptake of UNAC-LOW outputs by other EU projects.

The knowledge transfer between the partners have been running during the discussions at project meetings and field measurements for the calibration of underwater noise recorders.

List of publications

- 1) "Calibration standards for hydrophones and autonomous underwater noise recorders for frequencies below 1 kHz: current activities of EMPIR "UNAC-LOW" project" - *ACTA IMEKO, June 2018, Volume 7, Number 2, 32-38, 2018.*
- 2) "Signal-modelling methods applied to the free-field calibration of hydrophones and projectors in laboratory test tanks" - *Meas. Sci. Technol.*, 29, 085001, 2018

Project start date and duration:		01 May 2016, 36 Months
Coordinator: Alper Biber, Dr., TÜBİTAK, Tel: +90 262 677 31 59 E-mail: alper.biber@tubitak.gov.tr Project website address: http://empir-unaclow.com/		
Internal Funded Partners: Partner 1 TÜBİTAK, Turkey Partner 2 DFM, Denmark Partner 3 NPL, United Kingdom	External Funded Partners: Partner 4 CNR, Italy Partner 5 FOI, Sweden Partner 6 ISPRA, Italy	Unfunded Partners: